ELEMENTARY STUDIES IN BOTANY

COULTER

B. Hutchinson

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TWENTIETH CENTURY TEXT-BOOKS

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ELEMENTARY STUDIES IN BOTANY

BY

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PREFACE

It is seven years since *A Text-book of Botany* was published, and during this period there has been not only great progress in the knowledge of plants, but also much discussion concerning the effective use of plants in a high school education. It is natural that a discussion of this kind should lead to considerable diversity of opinion, and it is evident that no one is in a position as yet to decide the points at issue. Amid all the flux of opinion, however, there is evident a desire to relate plants more closely to the interest and to the need of high school students. This desire expresses itself in an extreme form when courses in "agriculture" are asked to be substituted for courses in "botany." This has brought a distinct temptation to publishers and to authors to "meet the demand" without much consideration as to its significance. It cannot mean that all that has proved good in the older method is to be abandoned, and an unorganized mass of new material substituted for it. It cannot mean that high school pupils are to become apprentices rather than students. It must mean that the structure and work of plants are to be so studied that this knowledge will enable the student to work with plants intelligently. In other words, it is intended to be the practical application of knowledge, rather than practical work without knowledge.

The present book, *Elementary Studies in Botany*, comprises two parts, intended to meet the two needs indicated above.

Part I, *Plants in general*, gives an account of the structure and work of plants simple enough to be understood by high school students of any grade, and brief enough to be com-

pleted in a half year. At the same time, illustrations are taken from economic plants, and practical applications in the handling of plants are suggested. In other words, this part is intended to develop some real knowledge of plants in connection with a practical outlook. In telling the story of plants, advantage is taken of the evolutionary point of view merely as a teaching device. This method of presentation has been very efficient in securing a grasp of the most important facts and in developing a perspective that lays emphasis where emphasis belongs.

Part II, *Plants in cultivation*, gives an account of the practical handling of plants in the field and in the garden, so far as this can be accomplished in a half year of work. It is the application to practice of the knowledge developed in connection with the work outlined in Part I. The great variety of crops and of cultural conditions forbids a series of specific directions in reference to even the principal crops. Even if this were possible, it would result in a series of directions resembling the recipes of a cookbook, some of them applicable in one locality and some in another, which is very far removed from the idea of a text-book. The plan is to develop some experience in handling the conditions that affect plants, so that any plant may be cultivated, in its appropriate conditions, with some knowledge of the things that must be done.

In case only a half year is given to Botany, Part I is recommended for use. It is complete in itself and represents the real basis for further progress. It will be possible to use Part II alone for a half year course, but the reasons for the practice involved will not be so evident as when it follows Part I. The two parts taken together represent a full year of work, which should combine the demand for training in science with that of training in the culture of plants.

Neither of the parts will serve its purpose unless it is used as a supplement to the teacher, to the laboratory, to the

experimental garden, and to field-work. Furthermore, it must be insisted that the sequence of each of the parts need not be the sequence used by the teacher. For example, in Part I, work on leaves, stems, roots, and seeds may come first, to be followed by the general story of the plant kingdom. The sequence may well differ according to the availability of material or the conviction of the teacher.

In the laboratory work, it is recommended that the individual work of the pupils be concerned with the gross structures and behavior of plants chiefly, reserving for occasional demonstration such structures as must be seen under the compound microscope. It is not necessary that the actual forms referred to in the book be obtained in every case. The plant kingdom is represented in every neighborhood, and it is far better to become acquainted with some of the local algæ, fungi, liverworts, mosses, etc., than to send for material that does not belong to the possible experience of the student. In the study of Seed-plants, and of course in Part II, it is necessary to arrange for the growing of plants under observation, and the plants selected should be those ordinarily used in gardens or fields, especially those that germinate quickly.

The illustrations have been cared for by my colleague, Dr. W. J. G. Land, and unless otherwise credited, all illustrations have been prepared for this volume or its predecessors.

John M. Coulter.

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PART I

PLANTS IN GENERAL

CHAPTER I

INTRODUCTION

1. **Occurrence in plants.** — Plants form the natural covering of the earth's surface. So generally is this true that a land surface without plants seems remarkable. Not only do plants cover the land, but they abound in waters as well, both fresh and salt. One of the most noticeable facts in regard to the occurrence of plants is that they do not form a monotonous covering for the earth's surface, but there are forests in one place, meadows in another, swamp vegetation in another, etc. In this way the general appearance of vegetation is exceedingly varied, and each appearance tells of certain conditions of living. Such plants as appear to the casual observer in a landscape or in a cultivated field are by no means the only plants. They are simply the most obvious or the most useful plants, but associated with them are hosts of plants simpler in structure and smaller in size, grading down to forms so small that they are visible only through a microscope. Any general view of the plant kingdom must include all plants.

2. **Plants as living things.** — It is very important to begin the study of plants with the knowledge that they are alive and at work. It must not be thought that animals are alive and plants are not. There is a common impression that to be alive means to have the power of locomotion, but this is far from true; and in fact some plants have the power of locomotion while some animals do not. Both plants and animals are living forms, and the laws of living that animals obey must be obeyed also by plants. It is for this reason that the term *biology* (the science that deals with

living things) applies to both plants and animals. There is so much confusion in the use of this word that it should be understood at the outset that biology deals with all living things, and that plants and animals are two groups of living things. To begin with the thought that plants are alive and at work is important, because this fact gives meaning to their forms and structures and positions. For example, the form and structure and position of a leaf have no meaning until it is discovered how these things enable the leaf to do its work.

3. **Plants and human needs.** — It is evident that the material welfare of the human race is largely based upon the work of plants. Not only do they furnish the fundamental food supply for all living things, but in innumerable minor ways they contribute to the necessities of human life. This important relation to human needs has resulted in grouping plants into those that are useful and those that are not, the inference often being that the latter are not so important for study as the former. If useful plants are to be made to yield the largest returns under cultivation, it is absolutely necessary to understand their structure and work. It is also true that plants can explain one another, and many "useless" plants can interpret useful ones. As a rule, the simpler plants are not used by man, but they are necessary to explain the more complex ones that he does use. It is further true that the scientific study of plants, whether useful plants or not, suggests methods of making useful plants more useful. For example, the practical work of agriculture can be improved only as the scientific work with plants points out the way. The most effective way to study useful plants, therefore, is to study the structure and work of plants in general.

4. **Plant work.** — Although many different kinds of work are being carried on by plants, all the work may be put under two heads: *nutrition* and *reproduction*. This means

that every plant cares for two things: (1) the support of its own body (nutrition), and (2) the production of other plants like itself (reproduction). In the cultivation of plants nothing is so important as to know about their nutrition and reproduction. Knowledge of the nutrition of plants enables one to secure vigorous plant bodies, and knowledge of the reproduction of plants enables one to secure desirable races of plants. Most cultivators of plants follow rules that they do not understand, but to learn such rules without learning plants makes one an apprentice rather than a student.

5. **Various aspects of plants.** — Plants are studied from numerous points of view, so that botanists are divided into many groups. The oldest subject of study was the *classification* of plants, which means discovering their relationships, assigning them to natural groups, and giving them names by which they may be recognized. In human society, such a study would be the recognition of family relationships, the grouping of people by families, and the use of names to distinguish individuals. Just as individuals are distinguished by two names, so two names are given to each kind of plant, and *Quercus alba* (white oak) is the name of a plant, just as *John Smith* is the name of an individual. Plants differ from human individuals, however, in that they have no family records, so that botanists are compelled to trust to certain resemblances to indicate the family connections. This means that plant classification must change as the knowledge of resemblances and differences increases, so that the work of classification demands continuous attention.

A second subject of study is the *structure* of plants. At first only such structures were included as could be seen with the naked eye; but with the invention and improvement of the microscope, the minute structures came to be studied also, so that it was possible to know how the body of a plant is made. This led later to a study of how the

body of a plant develops, from the egg to the adult; and still later to conclusions as to how plants develop from one another, a subject which is called *evolution*. If the classification of plants is likened to the recognition of the family connections and the names of people, the study of the structure of plants may be likened to the study of the structure of the human body and the details of its development from the egg to the adult.

A third subject of study is the *work* of plants. It must be remembered that plants are living things that use food, grow, and reproduce, and all this means the work of a living body. The study of the structure of plants is like the study of the parts of an engine and how they are put together, but the study of the work of plants is like the study of the engine in action. It is evident that a study of the structures of plants finds its meaning in helping one to understand the activities of plants, just as a study of the structure of the human body finds its motive in helping one to understand the human body alive and doing its work.

A fourth subject of study is the *diseases* of plants, which often ravage our crops. The chief causes of these diseases are other plants, so that this study involves a knowledge of the structure of two sets of plants, those that attack and those that are attacked. In addition to this, it involves a knowledge of two kinds of work, the work of the plant when in health and its work when diseased. The study of plant diseases is regarded as a very practical one, but it is evident that it cannot be carried on effectively without a previous knowledge of the structure and work of plants. Among the plants that induce disease in other plants are the bacteria, which are also conspicuous in causing certain diseases among human beings. These minute and peculiar plants require such special treatment for their study that they form a subject by themselves and demand a specially trained group of botanists.

A fifth subject of study is the *life-relations* of plants. Plants become related effectively to such things outside of themselves as light, water, soil, and other plants, and how this is accomplished is the subject referred to. Plants may be studied as individuals relating themselves to their surroundings, just as a human individual may be studied as he adjusts himself to the conditions of life in a city; or they may be studied in "vegetation masses," such as forests or prairies, just as groups of people in a city may be studied as they adjust themselves to other groups. One great natural vegetation mass is of such practical importance that it has developed the special subject of *forestry*.

A sixth subject is known as *plant-breeding*, and it has become of great scientific and practical importance. It means the growing of plants, generation after generation, under observation and control, and trying to discover the laws of inheritance, which we usually call *heredity*. This is the great scientific importance of plant-breeding. Its practical importance comes from the fact that the scientific work has suggested methods of improving our old plants, producing new ones, and guarding our crops against disease and drought. From the standpoint of our material interests nothing can be more important, for it lies at the basis of the world's food supply.

The six aspects of plants described above do not exhaust the list, but they are conspicuous illustrations of the fact that botany is not a single study, but includes many kinds of study.

6. **Simple and complex plants.** — Plants differ greatly not only in size, from microscopic forms to huge trees, but also in complexity of structure. Some plants are so simple that all regions of the body are alike, while others are so complex that the body consists of many kinds of structures. Although the structure of simple and complex plants is

very different, they do the same kinds of work. The work does not become more complex, but the structures developed to do it become more complex.

It is believed that the simple plants were the first members of the plant kingdom, and that plants gradually became more and more complex until the structure of our highest plants was reached. To understand the structure of the higher plants, it is necessary, therefore, to approach it as plants approached it, by beginning with simple forms and noting the appearance of one change after another until the greatest complexity is reached. It happens that the plants we use most are most complex, and therefore the tendency has been to study them first and often to study them only; but we are assuming in this book that a study of plants is intended to develop some real knowledge of plants.

Therefore, in the following pages we will begin with the simplest plants, and discover how the plant kingdom gradually became what it is. In this way we shall really know something of the structure and work of the plants we use most.

7. The four great groups. — It is customary to divide the plant kingdom into four great groups. These groups proceed from the simplest to the most complex plants, so that it will be helpful to obtain a glimpse of them in advance, as this will explain the order in which the plants are presented.

(1) *Thallophytes.* — These are the simplest plants, and therefore the lowest group. The name means "thallus-plants," and a thallus is a simple kind of plant body which will be understood when it is met. The conspicuous members of this group are called Algæ and Fungi, the former being the "seaweeds," although many of them live in fresh water, and the latter including such forms as mushrooms among their higher members.

(2) *Bryophytes.* — These are the first plants that inhabited the land surface. The name means "moss-plants," for the mosses are the most numerous representatives of the group.

(3) *Pteridophytes.* — These are the first plants that developed a woody system. The name means "fern-plants," for the ferns are the most numerous representatives of the group.

(4) *Spermatophytes.* — This highest group developed seeds, and the name means "seed-plants." Most of them also developed flowers, and they are sometimes called "flowering plants." It is the seed-plants that man uses most, but to understand and explain them, one must know the other groups.

CHAPTER II

THALLOPHYTES. — 1. Algæ

The Primitive Plants

8. **Definition.** — Algæ are called the primitive plants because they are thought to have preceded the other groups historically. This does not mean that they were necessarily the first plants, for plants that have disappeared, or that we have failed to recognize, may have preceded the Algæ. But in our present *flora*, as an assemblage of plants is called, the Algæ appear to be the forms that have given rise to the other groups. They are comparatively very simple, but not necessarily very small, for certain seaweeds become as bulky as do the higher plants.

The Algæ are of very little practical importance, hence their study is not due to the fact that men use them. But they are of very great scientific importance, because they illustrate the beginnings of the plant kingdom, and show how the important kinds of plant work are provided for in the simplest way. They are, in fact, a simple introduction to the study of plants.

9. **Water as a medium.** — If Algæ are the primitive plants, it follows that the plant kingdom began in the water, for Algæ grow in water or in very moist places. It seems to be true, also, that the most primitive Algæ, as well as those that gave rise to the higher plants, lived in fresh water; so that the numerous Algæ that live along the seacoasts are not the most primitive, nor have they given rise to higher plants. From this point of view, it follows that the fresh water Algæ are the most important to study.

To live in water as a medium means that all the structures and habits of such plants must be adjusted to water. Such plants can be explained only by remembering this fact. That plants living in the water may be relatively simple is illustrated by the fact that when plants live in the air they must be protected against drying, and this involves protective structures that water plants do not need.

10. **The cell** (Fig. 1). — The living substance of plants and animals is called *protoplasm*. It is the only substance that lives and works, and all the structures and work of plants are results of the activity of protoplasm. This protoplasm is organized into definite units, which may be thought of as protoplasm individuals, and these units or individuals are the *cells*. The simplest plants are single cells, while large and complex plants consist of millions of cells. It is in this sense that a cell may be called the unit of structure, and that a plant consisting of one such unit may be regarded as the simplest kind of plant.

Fig. 1. — Cells of a moss leaf: in each of the two complete cells the single large nucleus is seen, the numerous chloroplasts, and the granular-looking cytoplasm; the cell-wall surrounding each cell is very distinct.

Since a cell always includes substances that are not protoplasm, the term *protoplast* is used to indicate the living substance of the cell. The protoplast, therefore, is the living, individual unit, and protoplasm is the material of which it is composed. We shall use the term protoplast, therefore, for the living, protoplasmic individual.

Among plants, the semifluid protoplast usually surrounds itself with a *wall* (Fig. 1). This cell-wall is composed of material called *cellulose*, which is manufactured

by the protoplast, and which forms a delicate but tough and elastic layer.

The protoplast within its cell-wall is a very complex structure, which does a great variety of work. There are always at least two distinct regions or organs of the protoplast, which differ in appearance and in work. The *nucleus* is usually a globular mass of protoplasm (Fig. 1), lying in the midst of the protoplast, and marked off sharply by a delicate investing membrane. It is impossible to tell all that the nucleus does, but it is conspicuous in the work of cell-division, that is, the process by which a cell divides and forms two new cells.

The remainder of the body of the protoplast, in which the nucleus lies imbedded, is called the *cytoplasm*. It must not be thought that the cytoplasm is just a mass of protoplasm around the nucleus, for it has a structure of its own, and is especially conspicuous in the general processes of nutrition, which means the chemical and physical processes that take place in connection with the use of food.

In green plants, such as the Algæ, there is a third organ of the protoplast, called the *chloroplast* (Fig. 1). Chloroplasts are protoplasmic bodies of various forms among the Algæ, but among the higher plants they are usually more or less globular. There may be a single chloroplast in a cell or there may be several chloroplasts, and they are distinguished from the nucleus or from any other body in the cell by their green color, a color due to the presence of a green stain called *chlorophyll*. The peculiar work of the chloroplasts is to manufacture food from raw material, the details of which are outlined in the next chapter.

A very important fact to know in reference to the cell is that the protoplast is saturated with water when active. The water accumulates in the protoplasm until the cell swells and the wall becomes stretched and tense. This swollen condition of the cell is called *turgor*, and it is one

of the conditions necessary for its activity. Anything that withdraws water from the cell diminishes its activity, and if the loss of water continues, the protoplast becomes inactive and may pass into the condition called *dormancy*. In seeds, for example, the protoplasts may remain in this dormant condition for a long time, and then become active again when water is restored.

11. **Work of the cell.** — The work of the cell has been referred to in describing its parts, but it is important to emphasize it. The work of a plant of many cells is simply the sum of the work of all its cells. The work done by a living cell is so complex that it may be analyzed under several heads, but all of it may be grouped under two heads.

One is the work of *nutrition*, which includes everything that has to do with the securing and using of food. It is by this work that a plant maintains itself in vigor and in growth. The principal part of the body of a complex plant is concerned with the work of nutrition, and this part is called the *nutritive* or *vegetative body* of the plant.

The other kind of work is *reproduction*, which includes everything that has to do with producing new plants. In most plants the reproductive structures form a relatively small part of the body, but in one-celled plants or in simple many-celled plants nutrition and reproduction are carried on by all the cells.

12. **The vegetative body of Algæ.** — Algæ may be arranged in a series, beginning with those having the most simple bodies, and advancing to those having the most complex bodies. In this way one can appreciate the progress made by the plant body, and also the amount of such progress made by the Algæ. For the sake of clearness, we may think of the bodies of Algæ as representing different stages of general progress.

The first stage is represented by those Algæ whose bodies are single cells. Such plants are represented in the illustra-

tions by *Pleurococcus* (Fig. 2), very common as green patches on damp tree trunks, old board fences, damp walls and rocks, etc. When material from these patches, which often look like green stains, is observed under the microscope, it is discovered to be made up of innumerable green, spherical cells. The figure referred to (Fig. 2) shows a single individual and also the successive divisions that result in groups of individuals. In every case, each cell is a separate plant, quite independent of all the rest. In each plant (cell) shown in the figure the nucleus may be seen, surrounded by the granular-looking cytoplasm, and this in turn invested by a wall. It is evident that these minute individuals are equipped to do the work of nutrition and of reproduction just as truly as are the larger plants.

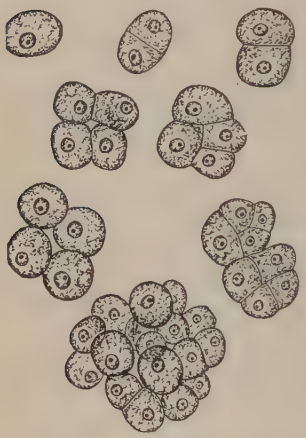


FIG. 2. — *Pleurococcus;* in the upper left-hand corner is a single plant (one cell), with its nucleus and cytoplasm surrounded by a cell-wall; in other figures the cell has divided, and has given rise to loose, irregular groups, in which each cell is an independent individual, and finally becomes separated from the rest.

A second stage is represented by those Algæ whose bodies are also single cells, but the cells cling together in such definite groups that the groups are called *colonies.* Examples of such plants are shown in Figs. 3 and 4. In Fig. 3 (*Glœothece*), the cells, as they are formed, are held together in a more or less irregular colony by a mucilage that is developed from the cell-wall material (cellulose). In Fig. 4, two colonies are shown: *Nostoc* (*A*), with the cells (individuals) held together in a definite row, so that the colony resembles a string of beads, and the mucilage is so abundant that many such colonies may be imbedded together in a single

jelly-like mass; and *Glœotrichia* (*B*), with its cells arranged as in *Nostoc*, but showing that the cells are becoming different, so that the base and apex of the colony are not alike. *Glœothece* (like *Pleurococcus*) is found in bluish green patches on tree trunks, fences, walls, etc.; and *Nostoc* occurs as small lumps of jelly in damp places. In these colonies the cells (individuals) are held together mechanically by the mucilage, but they seem to be as independent as if they were separate.

In the case of other colonies, such as the one shown in Fig. 5, the cells are much more closely related, being pressed against one another so as to flatten the walls that are in contact. Although the cells of this colony (*Oscillatoria*) are for the most part independent of one another, as shown by the fact that they may break apart and live independently, they work together in certain ways, notably in the characteristic swaying and revolving movements of the colony as a whole, movements that have given name to the plant. This interesting plant forms bluish green slippery masses on wet rocks, or it occurs on damp soil or freely floating on the water.

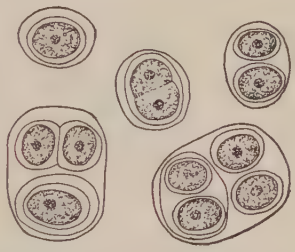


FIG. 3. — *Glœothece:* in the upper left-hand corner is a single plant (one cell), with its nucleus, cytoplasm, and wall, and also a covering of mucilage developed from the wall-material (cellulose); in the other figures, successive divisions are shown, resulting in an irregular colony of individuals held together by the investing mucilage.

When the individual cells of a colony work together in a still more intimate way, the colony of many individuals becomes the *individual of many cells*. This many-celled individual is the third stage in the progress of the plant body, and it is evident that there is no way of telling just when a colony becomes such an individual. The three general stages, therefore, are (1) the single cell, (2) the colony, (3) the many-celled individual. All of the remaining

illustrations of the Algæ show examples of many-celled individuals.

The bodies of many-celled Algæ have different forms, which may be referred to three general heads. It has been stated that cells divide. This is too complicated a process to describe here, but in general it means that the nucleus

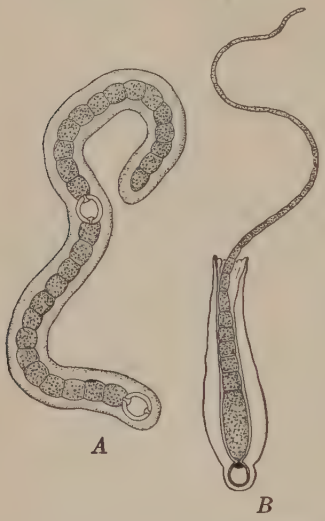


FIG. 4. — *Nostoc* (*A*) and *Glœotrichia* (*B*): the colony has the form of a beaded filament, imbedded in a mucilage sheath; in *B* the cells at the base of the colony are much larger than those above, showing that the individual cells are beginning to differ.

FIG. 5. — *Oscillatoria*: a very compact filamentous colony, in which the cells work together to produce the oscillating movement of the colony.

divides first and that a new wall is laid down between the two nuclei and extends through the cytoplasm to the old wall, making two cells half the size of the original one, just as a partition run through a room divides it into two smaller rooms. The new cells differ from the new rooms, however, in growing until each one is as large as the old cell.

In the first place, the cells composing the individual may divide freely in every plane, and this results in a massive body. This form is not very common among Algæ, because it is not the most favorable arrangement of cells for free exposure to water.

Fig. 6. — *Coleochæte:* a flat, plate-like body; from such an alga body the land plants were probably derived.

In the second place, the cells composing the individual may divide chiefly in two planes, at right angles to one another, and this results in a flat, plate-like body, which may be a single layer of cells in thickness, or several layers (Fig. 6). This form of body is more favorable for water exposure than the massive form, but it is not the most favorable.

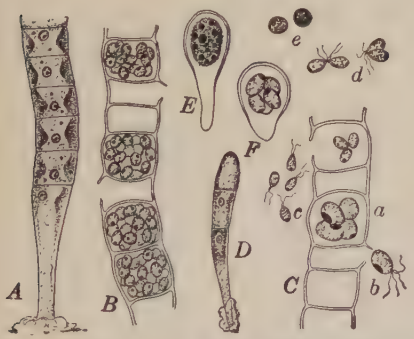


Fig. 7. — *Ulothrix: A*, base of filament, showing the holdfast cell and five of the ordinary cells above; *B*, four cells of a filament containing spores; *C*, showing one cell (*a*) containing four swimming spores, a free swimming spore (*b*), four escaped gametes (*c*), pairing gametes (*d*), and two oöspores (*e*) each of which has been produced by the fusion of two gametes; *D*, a young filament started by a swimming spore.

In the third place, the cells composing the individual may divide only or chiefly in one plane, or rather in a series of parallel planes, and this results in a filamentous body (Figs. 7, *A*, and 8). This is by far the most common form of body among the Algæ, especially the fresh-water forms, and it permits not only every cell to come into contact with water freely, but also the free swaying movements that are of advantage in water.

Another tendency in many-celled plants, which results in

the development of increasingly complex bodies, is for the cells to become unlike. This tendency to become different

FIG. 8. — *Cladophora:* a branching filament, each of whose cells contains several nuclei; in two of the cells swimming spores have developed, and from one of the cells some of the spores have escaped, showing the pair of cilia.

FIG. 9. — *Laminaria:* a common kelp, showing a complex body differentiated into holdfast, stalk, and blade (leaf-like portion).

is called *differentiation*. For example, in the filamentous body of *Ulothrix* (Fig. 7, *A*) the lowest cell differs from all

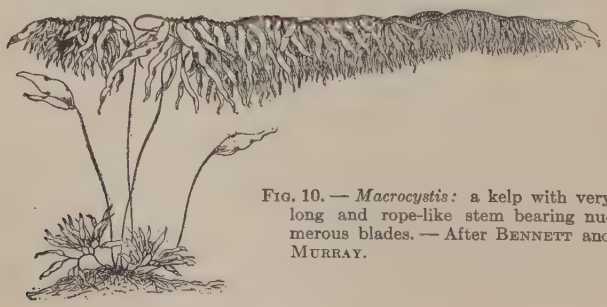


FIG. 10. — *Macrocystis:* a kelp with very long and rope-like stem bearing numerous blades. — After BENNETT and MURRAY.

the rest in size and form and contents, and serves as a holdfast for anchoring the plant. This anchoring cell is found in a great many filamentous forms, and shows that differentiation of form, etc., has to do with difference of work. Among the marine Algæ this differentiation becomes very great. For example, in such seaweeds as are illustrated in Figs. 9 to 14, there are complex holdfasts (often looking like roots), stalks (resembling stems), and leaf-like portions (which may just as well be called leaves). In these cases, not only is the body differentiated into different regions, but the cells composing each region are differentiated.

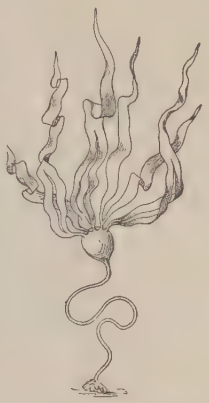


FIG. 11. — *Nereocystis:* a bladder kelp, showing the blades arising from the bladder-like expansion of the end of the stalk.

To summarize these statements in reference to the vegetative bodies of Algæ, it may be said that the Algæ begin as one-celled plants and become many-celled plants; that the cells of the many-celled forms become differentiated; and that finally the many-celled body becomes differentiated into different regions.

FIG. 12. — *Fucus:* fragment of rockweed, showing the forked branching, the swollen tips in which the sex-organs are produced, and the air bladders (three of them near the base).

13. **Reproduction.** — The preceding sections give an account of the vegetative body of Algæ. It now remains to consider the methods of reproduction developed by the Algæ. It must be understood that reproduction began as a relatively simple process, and that it became gradually more and more com-

plex, and therefore that there has been an evolution of reproduction. It must not be supposed that reproduction always became more complex as a vegetative body became more complex, for comparatively simple bodies may show an advanced method of reproduction, and many complex bodies have retained a relatively simple method of reproduction. In general, however, as plants advanced in the structure of their bodies, they advanced also in the methods of reproduction.

FIG. 13. — *Sargassum:* fragment of gulfweed, showing differentiation of the body into stem, leaves, and bladder-like floats (resembling berries).

14. **Vegetative multiplication.** — In the simplest plants, notably the one-celled forms, new individuals arise by dividing the old ones. For example, a one-celled individual works for a time as a vegetative body (engaged in the work of nutrition), and then the cell divides, producing two new individuals (Figs. 2 and 3). Since this kind of reproduction involves only vegetative cells, it is called *vegetative multiplication*, which means that it is simply a method of multiplying vegetative cells. When these multiplied vegetative cells are new individuals, the process becomes a kind of reproduction.

This seems to have been the first kind of reproduction among plants, and in many groups it is still the only kind of reproduction. Any group that has no other method of reproduction is regarded as one of very low rank, for the method of reproduction among plants is regarded as more important in ranking them than is the structure of their vegetative bodies.

It must not be supposed that vegetative multiplication occurs only among the lowest plants, for it is found in all groups of plants, even the highest. For example, when

potatoes are planted, the tuber, composed of vegetative cells, is cut into pieces, and each piece can develop a complete new plant. The leaves of some plants can be used in the same way; grapevines are usually started by planting "cuttings" or "slips" (bits of stem); and the process of "grafting" fruit trees really means starting new individuals

FIG. 14. — One of the Red Algæ, showing a very much differentiated and complex body.

from vegetative structures. When a new method of reproduction appears among plants, therefore, it does not mean that the old method is dropped, but that the new one is added.

A very important fact in reference to vegetable multiplication remains to be stated. When the cell of a one-celled plant divides, the result is two new individuals; but when

a vegetative cell of a many-celled plant divides, the result is usually the addition of new cells to the body, so that there are no new individuals, but the old individual *grows*. In other words, the cell-division which results in reproduction among one-celled plants usually results only in growth among many-celled plants. In a certain sense, any such growth is reproduction, for new cells are produced, but we are using the word reproduction in the sense of producing new individuals.

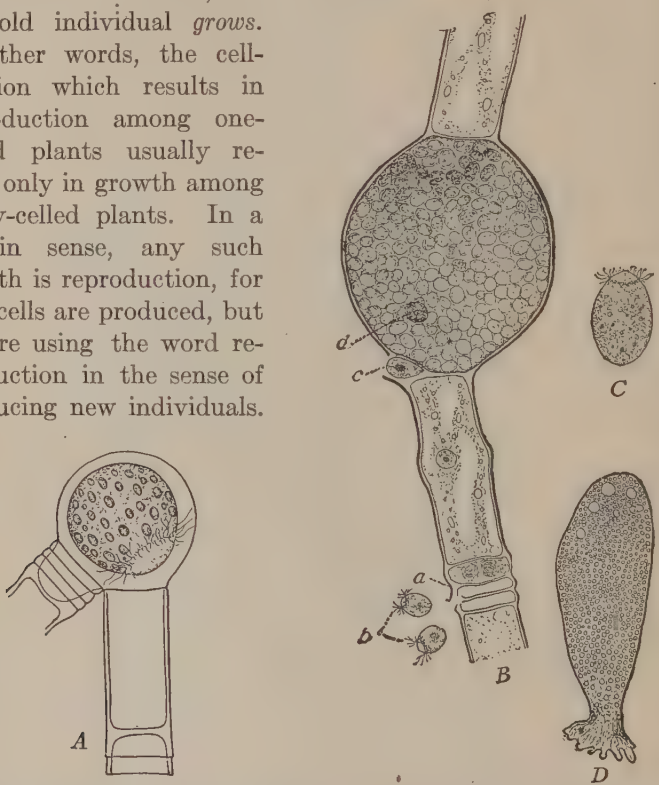


FIG. 15. — *Œdogonium: A*, part of a filament, one of whose cells has formed a single large swimming spore with a crown of cilia; *B*, part of a filament showing antheridia (*a*) from which two sperms (*b*) have escaped, a vegetative cell with its nucleus, and an oögonium (the large round cell) filled by a large egg packed with food and whose nucleus is seen (*d*), and which a sperm has entered (*c*); *C*, a swimming spore with its crown of cilia; *D*, a young plant developing from the swimming spore.

It is quite evident, therefore, that this process of cell-division goes on in all plants, and that in the lowest it is the only method of reproduction.

15. **Spore-reproduction.** — The second method of reproduction that appears among the Algæ is reproduction by *spores*. A spore is a special reproductive cell, as distinct from a vegetative cell. For example, in such a form as *Ulothrix* (Fig. 7), the vegetative body is a filament of cells (*A*). These cells perform the ordinary vegetative work of green cells when the conditions favor such work; but if the conditions change, they may begin to form spores (*B* and *C*). The protoplast that has been doing vegetative work divides, and this division may be followed by others, until the wall of the old vegetative cell incloses a number of new cells, which are the spores. The spores escape from the old inclosure into the water, and in *Ulothrix* they swim freely about by means of a tuft of four cilia (hairs) at the tip of each spore (*C*, *b*).

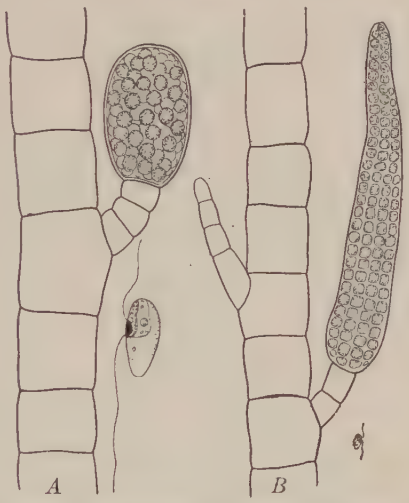


FIG. 16. — *Ectocarpus:* *A*, part of a filament showing a sporangium distinct from the vegetative body, and also an escaped swimming spore (enlarged) with its two lateral cilia; *B*, part of a filament showing a gametangium distinct from the vegetative body, and also an escaped gamete with its two lateral cilia.

These "swimming spores" are very characteristic of the Algæ, but the number and arrangement of the cilia vary. For example, in *Œdogonium* (Fig. 15, *A* and *C*) the cilia occur as a crown at one end; in the brown seaweeds there is a pair of cilia on one side of the spore (Fig. 16); in certain forms there is a single cilium; while the most common condition is a pair of cilia at the apex of the spore (Fig. 8).

It must not be supposed that spores are necessarily ciliated,

for spores of the Red Algæ, for example, have no cilia (Fig. 17) and are carried about passively by the water, while the spores of higher plants are carried through the air. Nor must it be supposed that spores are necessarily produced by the division of a protoplast; they generally are, but sometimes the whole protoplast escapes from its investing wall and is a spore (Fig. 15, *A*). Nor is a spore always naked (without a wall). Although swimming spores are usually naked, spores exposed to the air have walls, and sometimes very heavy walls. A spore is recognized, therefore, not by its cilia, its form, its covering, or its origin, but simply from the fact that it is able to produce a new plant. The process by which a spore starts a new plant is called *germination*, so that the business of a spore is to germinate.

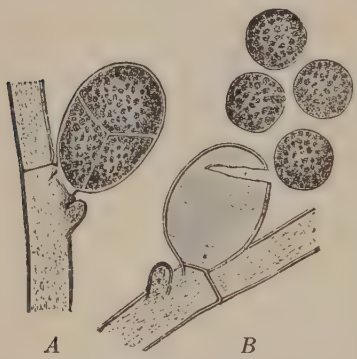


FIG. 17. — Portion of a red seaweed, showing a sporangium with its four spores (*A*), and another one (*B*) from which the spores (with no cilia) have escaped.

In most of the Algæ, spores are produced by the ordinary vegetative cells, that is, by cells that are a part of the vegetative body and form spores only when the conditions for vegetative work become unfavorable. Gradually, among the Algæ, however, the cell that produces spores becomes more and more distinct from the other cells, until finally it is entirely distinct, doing no vegetative work, and only producing spores, as in the brown alga shown in Fig. 16 and in the red alga shown in Fig. 17. Such a cell is called a *sporangium*, which means "spore-case." Although Algæ are characterized by an abundant formation of spores, it is only among the higher groups of Algæ that sporangia become differentiated from the rest of the body.

16. **Sex-reproduction.** — A third method of reproduction appears among the Algæ, and it represents the final stage in the progress of reproduction. This method was derived from spore-reproduction, and some of the Algæ illustrate this fact completely. In *Ulothrix* (Fig. 7, *B* and *C*), for example, a number of spores are produced by a single protoplast, the number of spores depending on the number of successive divisions. Naturally, the more numerous the divisions are, the smaller are the spores, so that in *Ulothrix* the number and size of the spores vary with the number of divisions. It is found that the smaller spores produce feebler plants, and that the divisions may become numerous enough to result in spores too small to produce plants at all. Under these circumstances it is observed that these small and incapable spores may pair with one another and fuse to form a single cell (Fig. 7, *C*, *d* and *e*), and that this cell can produce a new plant.

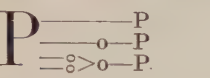
This act of fusing, by which a reproductive cell is formed, is the *sexual act*, often called *fertilization;* the two fusing cells, which are no longer spores because they cannot produce new plants alone, are *sexual cells*, usually called *gametes;* and the resulting cell with reproductive powers is an *oöspore*, sometimes called the *fertilized egg*. It is evident that gametes, among Algæ, are derived from swimming spores, and that the changes by which a swimming spore becomes a gamete are the changes that explain the origin of sex. It is also evident that the oöspore is a spore, because it produces a new plant, but it differs from the ordinary spore in the method of its origin. It is for this reason that it is distinguished by a prefix that means "egg," implying that it has been produced by the sexual act. When the word "spore" is used, the ordinary reproductive cell, not produced by the fusion of two cells, is meant. Very often the phrases "asexual spores" and "sexual spores" are used to distinguish these two kinds of spores, but the latter phrase is misleading, for

no spores are "sexual," the only sexual cells being the gametes.

Spores and oöspores are not produced by Algæ continuously, for under certain conditions Algæ may vegetate, without producing any spores; under other conditions they may produce spores freely; and under still other conditions gametes appear and oöspores are formed. In the ordinary course of the seasons, the spores are produced during the growing season and multiply individuals, in fact they do most of the reproduction. The gametes, on the other hand, usually appear towards the end of the growing season for the plant, and so the formation of the oöspores is about the last activity of the plant. The spores germinate at once, but the oöspores, appearing late in the season, develop heavy walls, remain dormant through the winter, and germinate at the beginning of the next growing season. In such plants, therefore, the oöspores are the only structures that remain alive through the winter. It may be said, therefore, that spores multiply the plant, while oöspores protect it through the winter and start it again. In those Algæ in which there is no sex, and therefore no oöspores, ordinary vegetative cells become heavy-walled and protect the plant through the winter.

17. **Life-history formulæ.** — The life-history of a plant means the complete history of its life, beginning at any point, for example, the spore, and continuing until spores appear again. It is helpful to express the outlines of a life-history by a formula, and the following formulæ illustrate the life-histories of the Algæ we have been considering. Vegetative multiplication may be indicated by P—P—P, etc., in which " P " stands for " plant," and which indicates that one plant produces another directly, without any special cells. Spore-reproduction may be indicated by P—o—P—o—P—o, etc., which indicates that the plant produces a spore which produces another plant, and so on. Sex-reproduction may be

indicated by P=°=°>o—P=°=°>o—P, etc., which indicates that the plant produces two gametes which fuse to form an oöspore which produces another plant, and so on. It must be remembered that in plants that produce sexual cells, all three ways of producing new plants are found, so that a real life-history formula for such a plant would be something as follows:



This simply indicates the three methods of producing new plants.

18. **Differentiation of sex.** — At the first appearance of sex, the gametes are alike in form and behavior, as in *Ulothrix* (Fig. 7, *C*, *d*). They are approximately the same in size, and are both swimming cells with the same arrangement of cilia, so that there is no visible sex-distinction. Plants with such gametes are sometimes called "unisexual plants," which means plants having only one sex. The phrase is misleading, for to have sex at all, there must be two sexes. What the phrase really means is that the sexes cannot be distinguished.

In other plants, however, the pairing gametes begin to show differences, one being larger than the other and correspondingly less active, until finally one is relatively very large and entirely passive, while the other retains its small size and activity. The increased size of one of the gametes means an increased nutritive power, but this gain has been accompanied by a loss of swimming power. This development of obvious differences between the pairing gametes is the *differentiation of sex*, whereby the two sexes become apparent. The large and passive gamete is female, and is called the *egg;* while the small and active gamete is male, and is called the *sperm*. For example, the illustration of *Œdogonium* (Fig. 15, *B*) shows a large egg (packed full of

food) within a swollen cell, and small ciliated sperms having escaped from small cells (*b*); while the illustration of *Fucus* (Fig. 20) shows a very large egg surrounded by numerous, small, and very active sperms.

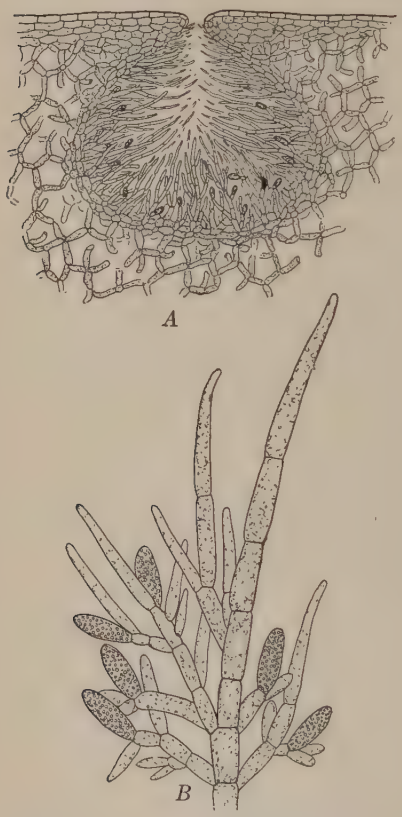


FIG. 18. — *Fucus*: *A*, a chamber in the body (see Fig. 12) containing branches producing antheridia; *B*, an enlarged view of a branch bearing antheridia, in which the sperms can be seen. — After THURET.

19. **Differentiation of sex-organs.** — In such Algæ as *Ulothrix* (Fig. 7, *C*), an ordinary vegetative cell, without any change of form, produces gametes. In other Algæ, as *Ectocarpus* (Fig. 16, *B*), the cells that produce gametes differ in form from the vegetative cells, just as the cells that produce spores (*A*) differ from them. Just as the spore-producing cells that become different from the vegetative cells are called sporangia (§ 15, p. 22), so these gamete-producing cells that become different are called *gametangia* ("gamete-cases"). A gametangium, therefore, is a sex-organ, that is, a structure that produces sex-cells (gametes).

When the gametes become plainly different, so as to be called eggs and sperms, the gametangia that produce them become different and receive distinguishing names. The

gametangium that produces an egg (usually only one) is an *oögonium* ("egg-case"), while the gametangium that produces sperms is an *antheridium* (a name whose meaning explains nothing).

There are two distinct stages in the evolution of oögonia and antheridia that ought to be recognized. In *Œdogonium* (Fig. 15, *B*), for example, the oögonia and antheridia are transformed vegetative cells; that is, cells which do vegetative work may later become oögonia or antheridia. But in *Vaucheria* (Fig. 21) and *Fucus* (Figs. 18, 19), for example, the oögonia and antheridia have never been a part of the vegetative body, but are set apart from the beginning as special branches. In these forms, therefore, the sex-organs have become completely differentiated from the rest of the body.

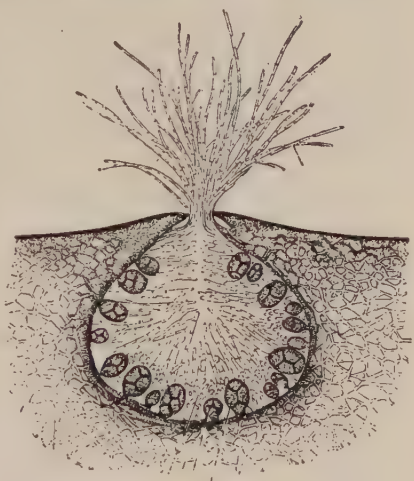


FIG. 19. — *Fucus:* a chamber in the body in which oögonia are produced. — After THURET.

20. **Differentiation of sex-individuals.** — There is another kind of sexual differentiation that must be recognized. In such Algæ as *Spirogyra* (Fig. 22), the two gametes look alike, both of them being large, but one of them remains passively in its cell, while its mate leaves its cell, squeezes through a connecting tube, and enters the other cell. The behavior of the two gametes, therefore, is different, and it seems proper to call the passive one female and the active one male. Furthermore, it is very common to find two filaments of *Spirogyra* lying side by side, all the opposing cells

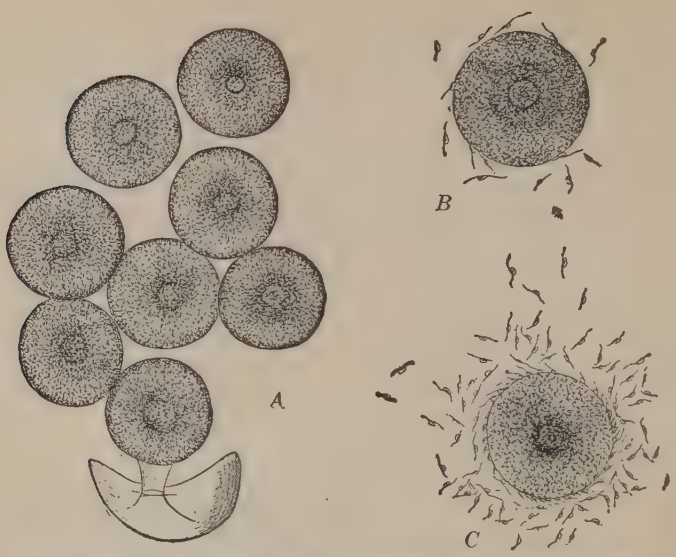


FIG. 20. — *Fucus: A*, the eight eggs discharged from the oögonium; *B* and *C*, egg surrounded by swarms of swimming sperms. — After STRASBURGER.

connected by tubes, and all of the cells of one filament empty, which means that all of the gametes of one filament have passed over into the cells of the other filament. If the

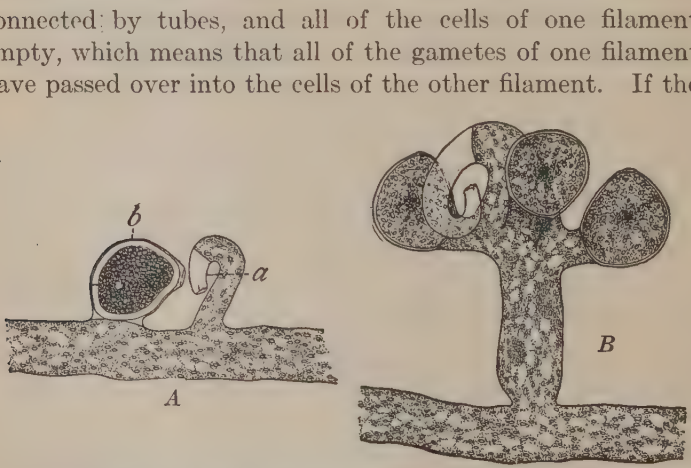


FIG. 21. — *Vaucheria: A*, part of a filament, showing the special branches producing an antheridium (*a*, emptied in this specimen) and an oögonium (*b*); *B*, another species, in which a single branch bears several oögonia and a terminal coiled antheridium.

active gametes are male, then the emptied filament is a male individual, and the receiving filament is a female individual. In such a case, therefore, there is a sexual differentiation of individuals, and in *Spirogyra* this occurs without any differentiation of gametes in appearance, and without any differentiation of sex-organs.

After the origin of sex, therefore, when the formation of gametes is an established habit, there are three kinds of differentiation: differentiation of gametes, of sex-organs, and of sex-individuals. These different kinds of differentiation may occur singly, or any two together, or all three together. When the last takes place, and we find plants with eggs and sperms, produced by distinctly set apart oögonia and antheridia, and these two kinds of sex-organs borne on different individuals, we have reached an extreme case of sexual differentiation.

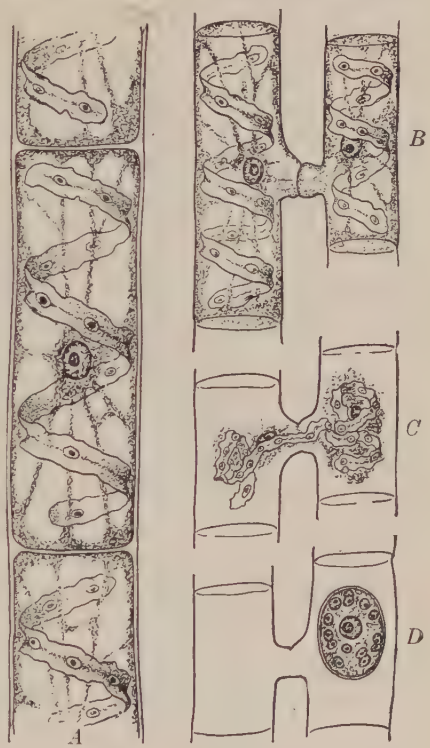


FIG. 22. — *Spirogyra: A*, part of a filament, showing one complete cell, with its central nucleus and its characteristic chloroplast (the spiral band); *B*, cells of two filaments developing the connecting tubes; *C*, the passage of one protoplast through the tube; *D*, the oöspore formed by the fusing of the two protoplasts; the emptied cell is therefore male and the cell containing the oöspore is female, and if all the cells of each filament are like the one shown, the filaments (individuals) are male and female.

21. **Summary.** — Algæ represent the beginnings of the plant kingdom, and all their structures are related to water as a medium.

The simplest body is a single cell, but among Algæ the body advances from the single cell, through cell-colonies, to the many-celled individual, whose form is prevailingly filamentous, although other forms occur. Among the higher Algæ, the many-celled body often becomes differentiated into different regions, notably among the marine Algæ.

The simplest form of reproduction is vegetative multiplication. In addition to this, Algæ developed reproduction by means of spores, which in most cases are swimming cells. Among the Algæ there appears also sexual reproduction, at first the gametes seeming to be alike, then differentiating into sperms and eggs. The two kinds of gametes at first are produced by ordinary vegetative cells, but later special cells produce them, which are therefore sex-organs.

CHAPTER III

FOOD MANUFACTURE

22. **Peculiar work of green plants.** — The Algæ differ from other Thallophytes in containing chlorophyll (§ 10, p. 10). The presence of this pigment is so common among plants that vegetation is thought of as being green, but very many plants are not green. Even those that contain chlorophyll are not always green in appearance, for this pigment may be obscured by others. For example, there are four groups of Algæ that are distinguished by their color, although all of them contain chlorophyll. The two conspicuous groups of fresh-water Algæ are called "Blue-green Algæ" (*Cyanophyceæ*) and "Green Algæ" (*Chlorophyceæ*) because in the former a blue pigment is associated with the green, giving the plant a bluish green tint, and, in the latter, chlorophyll is the only pigment. The two conspicuous groups of marine Algæ are called "Brown Algæ" (*Phæophyceæ*) and "Red Algæ" (*Rhodophyceæ*) because in the former certain brown and yellow pigments are associated with the green and often mask it completely, and in the latter a red pigment obscures the green.

The presence of chlorophyll in the Algæ gives them a peculiar power among Thallophytes, a power that all green plants possess. It is the power of manufacturing food. It is perhaps impossible to define exactly what is meant by food, but in general it means material that protoplasm can use in building up its body. All living things must use food, but only green plants can make it. This process, therefore, is one of the very greatest importance, for the existence of all plants and animals depends upon it.

Substances are said to be either *organic* or *inorganic*. An organic substance is one that is made by a living body; an inorganic substance is one that is usually made quite independently of a living body, as air, water, compounds in the soil, rock material, etc. The manufacture of food consists in taking these inorganic substances and making from them organic substances. It is this that green plants are able to do, and they manufacture food not only for their own use, but also for the use of plants that are not green as well as for the use of all animals. The food used by plants does not differ from that used by animals; the difference is that green plants have the added power of manufacturing food. A miller uses flour for his bread, just as every one else does, but he differs from others in also being equipped to manufacture his flour.

There are several general kinds of food, but the peculiar work of green plants has to do with only one of them, the kind called *carbohydrates*. If this name does not happen to suggest any kind of food, such common carbohydrates as sugar and starch will make the kind clear to every one. The importance of the manufacture of carbohydrates, which is the peculiar work of green plants, is recognized when it is known that in the manufacture of the other foods carbohydrates must be used. This means that although carbohydrates are not the only kind of food, they are the necessary start for all other kinds.

23. **The raw material.** — It is important to know the inorganic substances a green plant uses in the manufacture of carbohydrates. They cannot be rare substances, or vegetation would not be so common. They are water and carbon dioxide. The former needs no explanation; the latter is often called "carbonic acid gas," and is the so-called "impure" gas that accumulates in badly ventilated rooms. Carbon dioxide is everywhere in the air, in very small proportion (about three parts in 10,000), and is more

abundant in quiet waters, in which it is dissolved not only from the air, but also from the breathing and decay of the innumerable plants and animals that live in water. The Algæ naturally obtain it from the water in which they are living; while plants living on land obtain it from the air, chiefly through their leaves. The Algæ need no special equipment for obtaining water, for their bodies are exposed to it and it enters all the cells freely; but in the case of land plants, the special equipment is usually a root system into which water enters from the soil.

An important feature of these two substances that the green plant uses in carbohydrate manufacture, is that they are what are called "ultimate wastes" when food is being used. This phrase means that in our bodies, for example, carbon dioxide and water are disposed of because the body does not use them, and it does not use them because they are so difficult to break up as preliminary to forming new combinations. The ultimate wastes of living bodies, therefore, can be used by green plants as the raw materials for the manufacture of food. From food to waste is the work going on in all living bodies; from waste to food is the added work going on in all green plants.

24. **The agent.** — The active agent in the manufacture of carbohydrates is the chloroplast (§ 10, p. 10, and Fig. 1). As the name implies, a chloroplast consists of two conspicuous substances: (1) the living protoplasm (*plastid*), and (2) the green pigment (*chlorophyll*). They can be separated from one another by soaking green parts (as leaves) in alcohol, which extracts the chlorophyll and leaves the plastids colorless. Just what each of these substances does in the manufacture of carbohydrates is not known with certainty, but it is certain that both are necessary. The plastid is alive and the chlorophyll is not, but since the manufacture of carbohydrates is a chemical process, the chlorophyll may be the cause of some of the changes. In fact, a chloroplast

may be thought of as a chemical laboratory, which uses certain substances in the manufacture of others.

25. **The energy.** — Those who have studied physics are aware that energy, the power for work, is as real a thing as the material to work with. It is important, therefore, to discover the source of the energy used in the manufacture of carbohydrates. The chloroplast obtains this energy from sunlight, and it is known that chlorophyll is able to absorb energy from light. It is evident that this absorbed energy, in some form, is used in the chloroplast. It follows that carbohydrates can be produced by green plants only when exposed to the light, and that at night the process is suspended. In fact, many green plants may live through the winter, in the form of bulbs, tubers, etc., without any opportunity to manufacture food. It must be evident, therefore, that a process which is suspended for a considerable period during every twenty-four hours, and that may be suspended for months, is not a process of living, which involves the use of food, for living must go on continuously. It is simply a manufacture, which has nothing to do with the process of living except that it provides the material that is used in the process of living. It holds the same relation to the process of living that the baker holds to us in manufacturing bread.

It is important to observe that light is essential not only to the manufacture of carbohydrates, but also to the manufacture of chlorophyll itself. If light is withdrawn from a green plant for a considerable period, the plant loses its green color, as when a board lies for some time upon the grass, or when earth is heaped about celery to blanch it. When potatoes "sprout" in a dark cellar, the young shoots are pallid, but if exposed to light they become green.

26. **The process.** — The manufacture of carbohydrates by green plants has received a name suggestive of the process. It is called *photosynthesis*, which means putting together in the

presence of light. The word " photograph" shows the same use of the word light, and the process of " photography " shows the same activity of light in causing chemical changes. The first step in the process seems to be the " breaking up " of the water and carbon dioxide into their constituent elements. Those who have studied chemistry know that water is a combination of the two elements hydrogen and oxygen, both of them gases, in the proportion of two parts of hydrogen to one part of oxygen, so that the formula for water is H_2O. Carbon dioxide is also a combination of two elements, carbon and oxygen, and its formula is CO_2. To break up these two substances, so that the water splits into the two gases that compose it and the carbon dioxide splits into the gas and the solid that compose it, is a process that requires a great display of energy, in the form of heat, electricity, etc., when done in the laboratory; but it is accomplished by the green plant without any unusual display of energy.

Following the breaking up (analysis) of the raw materials, the elements are put together in new combinations, the " putting together " being the " synthesis " referred to in the name photosynthesis. It must not be supposed that a carbohydrate is the result of the first synthesis, for it is reached only after a series of chemical changes.

27. **The product.** — The final product of photosynthesis is reached when a carbohydrate is formed. If the raw materials and the final product are compared, certain important facts become evident. The simplest method of comparison is to use the following equation: $CO_2 + H_2O = CH_2O + O_2$. The first side of the equation represents the raw materials, and the other side represents the carbohydrate product and the oxygen left over. CH_2O is not the formula for a carbohydrate, but it may be called the carbohydrate unit, which by using various multiples becomes the formula of various carbohydrates. For example, a simple carbohydrate is $C_6H_{12}O_6$, in which 6 is the multiple, and most other carbo-

hydrates are multiples of 6. In examining the second half of the equation, it becomes evident (1) that the carbohydrate contains hydrogen and oxygen in the same proportion as in water, a fact which gives name to the compound (" carbohydrate " means carbon and water); and (2) that oxygen is freed as a waste product (or by-product) in the same proportion as it exists in carbon dioxide. The total result is to get the carbon out of the carbon dioxide and combine it with water, and therefore the process is often called the " fixation " of carbon. Hydrogen and oxygen are gases, so that carbon is the only solid that enters into the fabric of the plant, and this solid is obtained from a gas that exists in the air.

The carbohydrates thus formed in the plant are usually starches or sugars, and they are freely transformed into one another. It is often stated that green plants form starch, but the fact is that starch is only the visible form of the carbohydrate. It is visible because it does not dissolve in the cell sap, while sugar is invisible because it does dissolve. When more carbohydrate is manufactured than is being used, it becomes stored up in the form of starch, and therefore starch is spoken of as the *storage form* of a carbohydrate. On the other hand, when the carbohydrate is being used and is being carried around through the plant, it is in the form of sugar, for a substance must be in solution to be carried about, and therefore sugar is spoken of as the *transfer form* of a carbohydrate.

28. **The by-product.** — It has been noted that during photosynthesis oxygen is given off as a by-product. Nothing more than a statement of this fact would be needed if it were not connected with a persistent misconception in reference to photosynthesis. When it was first observed that green plants take in carbon dioxide and give out oxygen, it was natural to suppose that this gas exchange represented the respiration of plants. Since the gas exchange in the respiration of animals is just the reverse (taking in oxygen and giving

out carbon dioxide), the opinion became current that plants and animals differ in their "breathing." As a corollary to this opinion, it was pointed out that animals and plants supplement each other in this process, each taking in what the other gives off, and each living on what the other rejects. Since this impression is still current, its correction must be emphasized. It is clear that photosynthesis has nothing to do with respiration, for respiration is associated with what may be called the act of living, and therefore is carried on by every living thing. If respiration stops, the plant or animal body is dead; in fact, we use respiration as an evidence of life. Therefore plants and animals "breathe" alike, both taking in oxygen and giving out carbon dioxide; but green plants can carry on the process of photosynthesis also, in connection with which it takes in carbon dioxide and gives out oxygen. The confusion arose from the fact that during the day, when photosynthesis is going on, the amount of the gas exchange involved in the manufacture of carbohydrates is so much greater than the amount involved in respiration that the latter was not noticed; but if the observation had extended into the night, it would have been discovered that only the gas exchange of respiration was being carried on.

It may be useful to contrast photosynthesis and respiration sharply as follows: photosynthesis occurs only in green cells, requires light, uses carbon dioxide, liberates oxygen, makes organic material, and accumulates energy; while respiration occurs in every living cell, does not require light, uses oxygen, liberates carbon dioxide, uses organic material, and uses energy.

29. **Manufacture of proteins.** — Carbohydrates are by no means the only foods, and therefore photosynthesis is not the only process of food manufacture. Another conspicuous group of foods is the *proteins*, which may be regarded as foods in the most advanced stage, since the living protoplasm is largely composed of proteins. Carbohydrates,

therefore, may be thought of as the first stage of food, and proteins as the last stage.

The constitution of proteins is not known, so that their manufacture is not understood. It is known that neither light nor chlorophyll is required, for the process goes on in living cells removed from light, and in plants containing no chlorophyll. It is known, however, that carbohydrates are used, and that to the carbon, hydrogen, and oxygen supplied by them, the elements nitrogen, sulphur, and often phosphorus are added. It is important to know the sources of these new elements that enter into food manufacture. They are not used by the plant as free elements, but are obtained from their combinations in what are called *salts*. For example, salts containing these elements occur in all soils upon which plants can grow, and these same salts are dissolved in the water in which Algæ grow. In land plants, they enter through the roots, while in Algæ they enter wherever the plant is exposed to water.

30. **Assimilation**. — While the processes of food-manufacture are being considered, it will be helpful to define the use of food. There is an intermediate process called *digestion*, which simply means the conversion of foods into transfer forms, usually soluble forms. For example, digestion transforms insoluble starch into soluble sugar. It is evident, furthermore, that only those foods need to be digested which are not in transfer form.

The process by which foods are used in the manufacture of protoplasm is called *assimilation*. Protoplasm is the living body and it uses food to construct more protoplasm.

31. **Respiration**. — Everything about the plant is a product of protoplasm, and in doing the great variety of work that goes on in a living body the protoplasm " breaks down," using itself up continually in the manufacture of products. Of course this explains why it must be assimilating all the time, so that its body may be continually built up. This

process of breaking down the protoplasmic body is *respiration*, and one of the superficial indications that respiration is going on is that oxygen is taken in and carbon dioxide is given off. This gas exchange, therefore, is not respiration, but is merely the external evidence that the process is going on.

32. **Summary.** — The peculiar work of green plants is to manufacture carbohydrates. The raw materials used are carbon dioxide and water, which the chloroplasts, with energy obtained from sunlight, use in the manufacture, a certain amount of oxygen being given off as a by-product. The carbohydrates thus manufactured are the basis of other foods (as proteins). Water and carbon dioxide, therefore, are not foods, but materials from which foods are manufactured. The food of all plants and animals is the same, and when used it is digested (if necessary) and assimilated (built up into protoplasm); and the evidence that the living protoplasm is working is that respiration is going on, an external indication of which is the entrance of oxygen and the escape of carbon dioxide. All plants and animals, therefore, use the same food and " breathe " in the same way, but only green plants can manufacture food from material that is not food.

CHAPTER IV

THALLOPHYTES — 2. Fungi

Dependent Plants

33. **The dependent habit.** — The Algæ are said to be independent plants because they can manufacture carbohydrates from inorganic material. This means that they do not depend upon any other plants or animals for their food supply, and therefore could live and work if they were the only organisms in existence. The Fungi, on the other hand, are those Thallophytes that have no chlorophyll, and therefore cannot manufacture carbohydrates. This means that they must depend upon other plants and upon animals for their food supply, and that they could not exist in the absence of green plants.

It must not be supposed that Fungi are the only dependent plants, for even among seed-plants there are those without chlorophyll, as Indian pipe and a number of orchids, that are compelled to obtain their food from other organisms. But the Fungi represent by far the greatest assemblage of dependent plants.

34. **Parasites and saprophytes.** — If Fungi must obtain their food from other organisms, it should be recognized that there are two general conditions in which this food occurs. It is either a part of the living body of a plant or animal, or material that has been produced by a living body and is no longer connected with it. For example, when the rust fungus attacks wheat, it is obtaining food from living plants;

but when a mold fungus attacks bread, it is obtaining food from material produced by living plants, but no longer connected with them. Fungi (like the rust) that attack living bodies are called *parasites;* while those (like the mold) that attack organic material no longer connected with a living body are called *saprophytes.*

It must not be thought that parasite and saprophyte are terms of classification. They refer only to two sources of food supply, and there are many Fungi able to obtain food from both sources. Naturally, some Fungi are usually parasites, and some are usually saprophytes, but they all obtain food from any available source. In fact, many so-called parasites do not attack the living cells of plants, but live in the vessels carrying water (" sap ") and thus choke them. It is convenient, however, in a general way, to distinguish between the parasitic habit and the saprophytic habit, for while the former often brings trouble to living plants and animals, the latter does not.

The plant or animal attacked by a parasite is called its *host,* and when the attack interferes with the vigor of the host, the latter is said to be *diseased.* It is important to understand what is meant by *disease,* for there is often confusion in using the word. For example, rust is often spoken of as a disease of wheat and other cereals, when, in fact, rust is the parasitic fungus that induces the disease.

The range of attack by parasites is extremely variable. For example, some parasites attack many kinds of plants; others attack only a certain family of plants; others attack still smaller groups; and still others attack only one kind (species) of plant, and often can select that species with more certainty than does the botanist. Parasites differ also in the amount of the host attacked. For example, some attack the whole plant; others attack only certain general regions (as shoots or flowers); while still others may be restricted to a single kind of organ.

35. **Economic importance.** — It was said of Algæ that they are of little or no economic importance, but of very great scientific importance in the history of the plant kingdom. This statement may be reversed for Fungi. They are of little scientific importance in the history of the plant kingdom, but of very great economic importance. In defining parasites, it was stated that they induce disease, and when it is realized that these plant parasites are responsible for many diseases that ravage crops, domesticated animals, and the human population, it would be hard to exaggerate their economic importance. It is on account of this importance that the parasitic fungi have received so much attention, for they represent an enemy against which men must always be on guard.

On the other hand, the work of the saprophytes is often beneficial. They may be regarded as natural scavengers, decomposing dead bodies and organic waste into their constituent elements or inorganic compounds. Advantage is taken of this process in various manufactures, such as the manufacture of alcohol from sugars, the fermentation of fruit juices in the manufacture of wines, the "raising" of bread dough by yeasts, etc.

36. **Origin of Fungi.** — It is a common belief that Fungi are Algæ that have lost the power of food-manufacture. Some Algæ and Fungi resemble one another so closely in structure that this belief seems reasonable; but most Fungi differ so much from all known Algæ that such a connection does not seem convincing. It is easy to understand how Algæ might lose the power of food-manufacture if exposed to an available food supply. For example, certain Algæ inhabit cavities in the bodies of green plants, and the food manufactured by these plants might be available for the Algæ, which might thus gradually become dependent.

Perhaps the best reason for believing that Fungi are degenerate Algæ is that probably the two groups existed

together before any other plants appeared, and that under such conditions Fungi could not appear until after Algæ

Fig. 23. — Bacteria of various kinds, mostly ciliated; *F* is the bacterium of typhoid fever, and *H* that of cholera. — After Engler and Prantl.

had started the business of food-manufacture. However, we know nothing of the history of plants before the Algæ and

Fungi that we see, so that any statement as to the relationship of these two groups is at best a hypothesis that may or may not be true.

37. **Bacteria.** — One of the prominent groups of Fungi is called *bacteria*, a name that has become very familiar in connection with the study of human diseases, sanitation, etc. Once bacteria were spoken of as "germs of disease," and were often thought of as minute animals. It is impossible to overestimate their importance to man from the stand-

FIG. 24. — Some bacteria of fermentation and disease: bacteria of souring milk (*A*), of vinegar (*B*), of diphtheria (*C*), of tetanus or lockjaw (*D*). — After FISCHER.

point of his personal interest. It is this fact that has stimulated the study of bacteria to such an extent that it has become a special subject known as *bacteriology*.

Bacteria include the smallest known plants, some of them being visible only under the highest powers of the microscope, and doubtless there are some that are even smaller, and have remained invisible. They are single cells (spherical, oblong, rod-like, or curved), and occur either singly or held together usually in filaments (Figs. 23 and 24). Often they have cilia and swim freely, and this fact probably first suggested that they are minute animals. They occur everywhere, in all waters, in air, in soil, in all plants and animals (living or dead). A striking feature is their power of enduring some conditions that would destroy other plants, as extremes of temperature, great dryness, etc. Their only

method of reproduction is by means of vegetative multiplication, but this multiplication proceeds with such remarkable rapidity that a single cell may give rise to millions of cells in twenty-four hours. Some of the important work done by bacteria may be outlined as follows.

Some bacteria attack dead bodies of plants and animals, or organic material produced by plants and animals result-

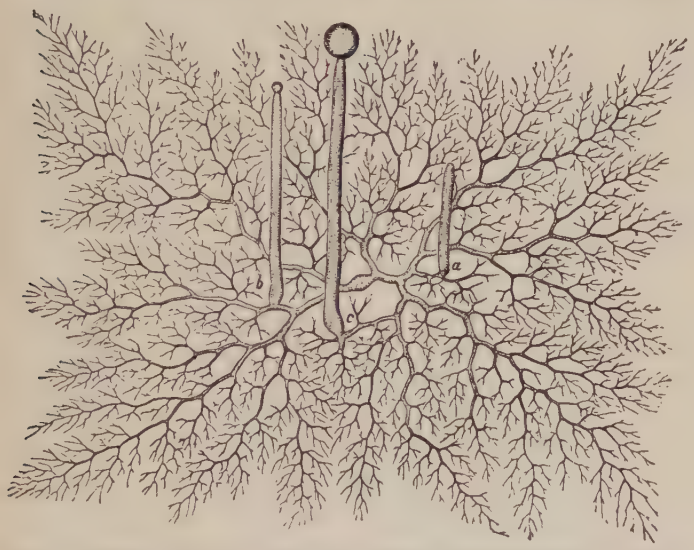


FIG. 25. — Diagram of *Mucor*, showing the profusely branching mycelium and three sporophores, one of which bears a sporangium. — After ZOPF.

ing in what is called putrefaction or fermentation (Fig. 24, *A* and *B*). All of this work is of large service, but special use is made of certain of the fermentations, as already mentioned.

Other bacteria attack living plants and animals, producing various diseases, which are regarded as important so far as they affect our cultivated plants, our domesticated animals, and ourselves. Many of the common and most dangerous diseases of the human race, such as typhoid fever (Fig. 23, *F*),

diphtheria (Fig. 24, *C*), tuberculosis, and pneumonia, as well as some very destructive plant diseases, are caused by these bacteria.

Other bacteria live in the soil, and are of enormous importance in changing the materials of the soil and in adding new material to the soil, making it possible for other plants to use the soil. The great importance of these bacteria to agriculture is coming to be recognized.

38. **True Fungi.** — The bodies of true Fungi consist of filaments, which may be interwoven more or less compactly. For example, the weaving may be so loose that the body is as delicate as a spider web, or it may be so close that the body is almost as compact as felt. This filamentous body is called a *mycelium* (Fig. 25).

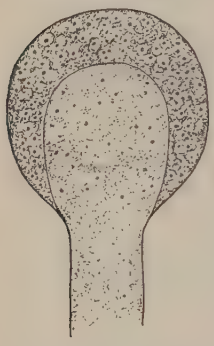


Fig. 26. — Section of a sporangium of *Mucor* developing, and showing how the partition wall is pushed up into the cavity of the sporangium.

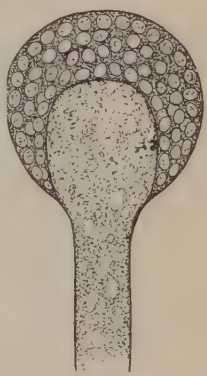


Fig. 27. — Section of a mature sporangium of *Mucor*, showing the spores.

Molds. — The ordinary mold that appears as a white furry growth on stale bread (when kept moist and warm) may be taken as an illustration (Fig. 25). The mycelium must be related to its food supply, and therefore it is observed spreading over the surface of the bread, evidently being a true saprophyte. Branches from the mycelium penetrate the bread, and into them the nutrient solution from the bread passes. These branches that receive the food supply are called *haustoria* ("suckers"), and of course are a very essential part of the vegetative body.

Under suitable conditions, the prostrate mycelium also

gives rise to erect branches, whose tips become sporangia that produce vast numbers of spores that are scattered by currents of air (Figs. 26 and 27). These spore-bearing branches are well called *sporophores* ("spore-bearers").

Under other conditions, two neighboring mycelia form special branches that come together in pairs, tip to tip (Fig. 28). Each tip is cut off from the rest of the body by a wall, and the protoplasts of the two cells thus formed fuse, and a heavy-walled oöspore is the result. This means that each tip-cell is a gametangium, and that the fusing protoplasts are gametes. The gametes and the gametangia usually look alike (Fig. 28, *B*) and behave alike, but it is found that the mycelia are sexually different. In some cases the gametangia differ in size (Fig. 28, *C*), so that a sexual difference is evident. Although one mycelium looks very much like another, the formation of oöspores will not take place unless sexually different mycelia are brought together. For this reason the mycelium of molds may be grown indefinitely without producing oöspores.

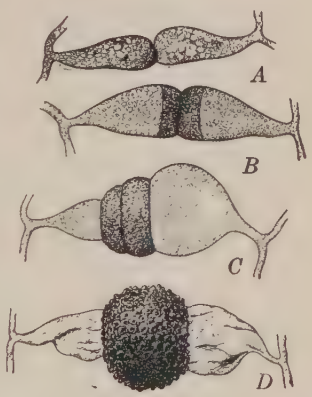


FIG. 28. — Sexual reproduction of *Mucor*: *A*, the sexual branches in contact; *B*, the two sex-organs (gametangia) cut off by walls; *C*, the two pairing sexual branches and their gametangia unequal in size; *D*, the oöspore formed by the fusion of the protoplasts of the two gametangia.

The four things to observe, therefore, in the study of a true fungus, are the mycelium, the haustoria, the sporophores, and the sexual apparatus. A comparison of the mold with some other Fungi will illustrate how these four things vary.

Downy mildews. — There is a group of Fungi called the "downy mildews," which attack a great many plants, producing such diseases as potato rot, grape mildew, and com-

mon diseases on many vegetables. In this group the mycelium lives upon a plant host and is a true parasite. It does not spread upon the surface of the host, but penetrates within it, crowding its way between the living cells of the host (Fig. 29). Thus it is not only a parasite, but also an internal parasite. From its position against the living cells of the host, the mycelium sends its haustoria through the cell-walls (Fig. 29), and into these haustoria the cell-sap of the protoplast enters, so that the protoplast is dried out and dies. When a mycelium is living in this way in the interior of a leaf, as a grape leaf, the drying out and killing of the leaf-cells by the haustoria is shown by the discolored and finally brownish spots that appear on the leaves.

FIG. 29. — Downy mildew: branch of mycelium in contact with two cells of a host plant, and sending into them branching haustoria. — After DE BARY.

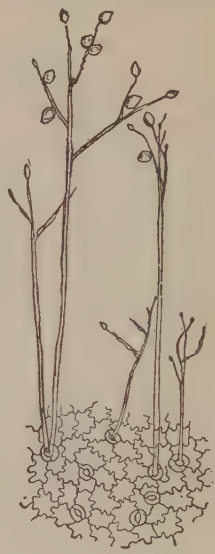


FIG. 30. — Downy mildew: sporophores emerging through the "breathing pores" of a leaf, branching, and bearing spores; this form causes the potato rot. — After STRASBURGER.

Then the mycelium sends its sporophores to the surface of the host (Fig. 30), for the spores must be formed where they can be scattered; and it is the sporophores coming to the surface that represent the only part of the parasite visible outside the host. These spores are not formed within sporangia, but are formed by cutting off the tip of the sporophore

or the tips of its branches (Fig. 30). The sporophores reach the surface of the host either by emerging singly through numerous openings ("breathing pores") in the epidermis

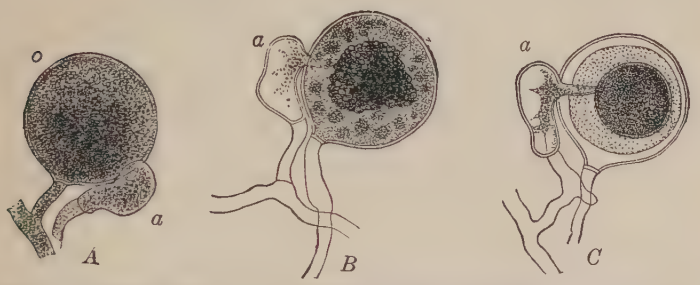


FIG. 31. — Downy mildew: *A*, oögonium (*o*) with antheridium (*a*) in contact; *B*, tube from antheridium penetrating oögonium; *C*, oögonium containing the oöspore. — After DEBARY.

(Fig. 30), or by massing together and pushing up the epidermis until it dries out and ruptures. In this latter case, the first appearance on the surface is a whitish blister.

Later, the internal mycelium develops the sexual branches, which in this case are so different that they can be recognized as oögonia and antheridia (Fig. 31). The antheridium sends out a tube that pierces the wall of the oögonium and through which the contents of the antheridium are discharged into the oögonium, in which the heavy-walled oöspore is formed (Fig. 31). These sex-organs and the oöspores are not brought to the surface of the host, as are the sporophores, for when the oöspores are ready to germinate during the following spring, the host tissues inclosing them have decayed.

FIG. 32. — Lilac leaf covered with mildew: the shaded regions representing the mycelium with its numerous spores (giving the dusty appearance), and the black dots the spore-cases.

Powdery mildews. — There is another group of mildews (sometimes called "powdery mildews" to distinguish them from the "downy mildews") that will illustrate the third relation of the mycelium to the food-supply. One of the most commonly observed among them is the lilac mildew. It is seen on every lilac bush as whitish, dusty-looking patches on the leaves (Fig. 32); in fact, whole bushes sometimes appear as if completely covered by street dust. Under the microscope it is seen that this whitish material on the leaves is the mycelium of a fungus, which in this case is an external parasite. The haustoria penetrate the walls of the epidermal cells of the host, which are really not vital cells, so that such mildews may be very abundant upon a plant without destroying it or seriously interfering with its vigor; in fact, almost all plants have mildews.

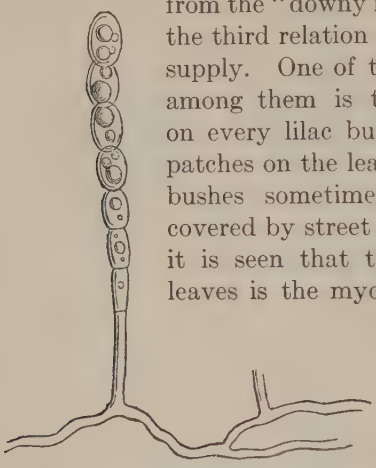


Fig. 33. — A sporophore of a mildew with its row of spores. — After Tulasne.

The mycelium produces sporophores abundantly, and it is really the numerous spores that give the dusty appearance to the leaves. These spores are formed as are those of the downy mildews described above, except that they are cut off in chains by an unbranched sporophore (Fig. 33).

Later the sex-organs appear, very minute and not often seen, but the result of their work is always seen. This result is a heavy-walled case (Fig. 34), which

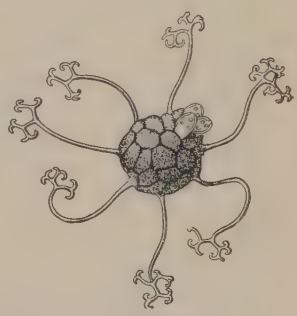


Fig. 34. — A spore-case of a mildew, showing its heavy wall, its conspicuous appendages, and the sacs (containing spores) squeezed out through a break in the wall.

looks like a brownish or blackish dot on the lilac leaf (Fig. 32). When this case is broken open, it is found to contain several thin-walled sacs (sometimes only one), within which are spores (Fig. 34). These heavy-walled cases, always bearing characteristic "appendages" (Fig. 34), are the protected structures that last through the winter, and it is their spores that start new mycelia during the following spring. How fertilization results in this case containing sacs with spores, is not necessary for the beginner to know.

Fig. 35. — Summer spores of the wheat rust, which form the rusty lines on the wheat; notice the two nuclei in each spore.

The three illustrations given show how the mycelium and the structures it produces are related to food-supply as saprophytes (as the molds), external parasites (as the powdery mildews), or internal parasites (as the downy mildews).

Fig. 36. — Winter spores of the wheat rust; each spore has two cells, and each cell has two nuclei.

The true Fungi are so very numerous that they cannot be presented in a brief account. It is impossible to give examples even of those that are of great economic importance; but the above illustrations will give some idea of the structure of the body and its relations to the food-supply, and two other illustrations are added because of their general interest.

Wheat rust. — The rusts are destructive parasitic Fungi that attack very many plants, but public interest is chiefly directed to those that attack the great cereal crops, chief among which is wheat. The presence of rust in a wheat field is noticed first by the appearance of reddish, rusty-

looking lines on the stem and leaves of some of the plants. These lines extend and multiply, new plants become infected, and presently the whole field may become rusty. A microscope shows that this rusty looking material is made up of spores (Fig. 35); and it is evident that they have been brought to the surface by sporophores arising from an internal mycelium.

Later in the season, after the wheat has been harvested, there appear black lines on the stubble, the so-called "black rust." It does not belong to the stubble any more than to the rest of the plant, but it appears so late in the season that ordinarily there is only stubble left to appear

FIG. 37. — Winter spores of the wheat rust germinating, each filament consisting of four cells, and each cell sending out a delicate branch that produces at its tip a spore (early spring spore). — After TULASNE.

FIG. 38. — A cluster-cup (on barberry) of the wheat rust, containing rows of spring spores; each spore contains two nuclei.

upon. The "black rust" consists of heavy-walled spores that arise from the same mycelium (Fig. 36). There are thus two kinds of spores produced by the mycelium on the wheat; one kind during the season, by means of which the rust is spread; the other kind towards the end of the season,

by means of which the rust is carried through the winter. Very naturally, the former are often called "summer spores" (Fig. 35), and the latter "winter spores" (Fig. 36).

Early in the following spring the winter spores germinate, producing very short filaments, and these filaments put out a few slender branches, at the tip of each of which a spore is formed (Fig. 37). These little filaments that produce the third kind of spore are not parasites at all, for they are not related to any host. The spores they produce may be called the "early spring spores."

The early spring spores germinate when they fall upon the right kind of host plant. In the wheat rust first studied in England, the host plant that received the early spring spores was found to be the barberry. The spores form an extensive internal mycelium in the barberry leaves, and this mycelium sends to the surface (usually the under surface) groups of sporophores with abundant spores, the groups forming reddish patches that sometimes cover the under surface of the leaf (Fig. 38). This is the fourth kind of spore, and may be called the "spring spore."

FIG. 39. — Mycelium of a mushroom producing sporophores (young mushrooms, called "buttons"). — After SACHS.

The spring spores that fall upon young wheat plants germinate and form the mycelium that feeds upon the wheat, and that produces the summer and winter spores with which this account began.

In the life-history of wheat rust, therefore, there are four

kinds of spores, three kinds of mycelia (two of which are parasitic), and two different hosts. This probably represents the most complex life-history of a fungus, and illustrates the great difficulty of studying and combating the rusts. Of course, the rusts that attack the wheat fields of the United States do not use usually the barberry as the "intermediate host," since with us barberry bushes are not common enough to serve such a purpose. But our several kinds of rusts use

FIG. 40. — A common edible mushroom; really a sporophore.

other intermediate hosts, which are plentiful enough to insure a continuation of the rust.

Mushrooms. — Even a very short account of Fungi would be incomplete without some mention of the mushrooms, which are perhaps the Fungi best known to most people. There is no difference between mushrooms and toadstools, except that the latter name has been applied to those mushrooms that are poisonous. Very closely related mushrooms may differ in this particular, so that the two names cannot be used as terms of classification. For example, *Boletus edulis*,

as its name implies, is an edible form; while its near relative, *Boletus Satanas*, as its name implies, is a deadly form.

The mycelium of a mushroom extends widely in the decaying material in which it grows (Fig. 39). In some cases it extends under the bark of trees and does them great damage. Every one must have seen these thready growths in forest soil or in rotting logs and stumps. This mycelium sends up sporophores, which are the structures commonly called mushrooms (Fig. 40). They differ from the ordinary sporophores of Fungi in consisting of many branches organized together in a complex structure. They may be called "compound" sporophores, to distinguish them from the simple sporophores of the other groups. These sporophores produce a vast number of spores (Fig. 41),

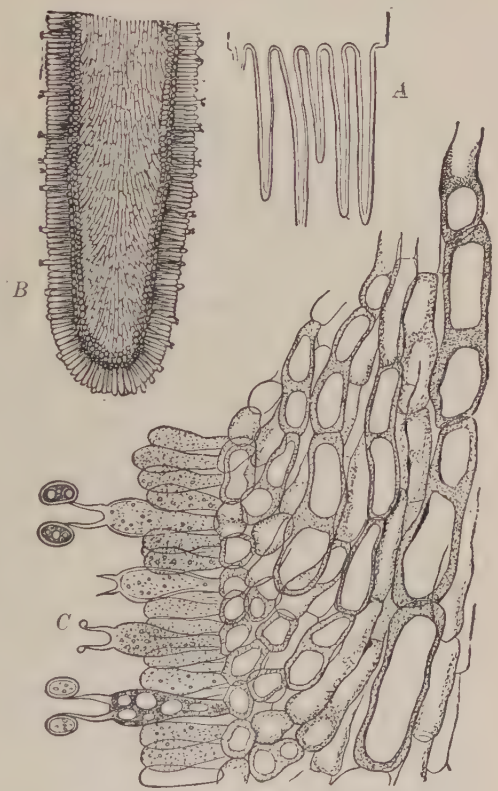


FIG. 41. — Sections through gills of a mushroom: *A*, gills hanging from the cap (*pileus*); *B*, single gill enlarged, showing the basidium layer; *C*, much enlarged view of a portion of a basidium layer, showing the basidia bearing spores. — After SACHS.

which on germination produce new mycelia, so that the life-history of a mushroom is very simple compared with that of a rust.

These sporophores are not always of the umbrella-form commonly associated with the name mushroom. Very often they form brackets on stumps and tree trunks (Fig. 42);

FIG. 42. — A tinder fungus growing on a red oak.

sometimes they are merely like incrustations; while in the so-called "puff-balls" they are globular (Fig. 43).

The groups of true Fungi. — There are three great groups of true Fungi recognized, which may be defined briefly as follows.

In the first group the mycelium has no cross walls, except as

sporangia or spores or sex-organs are cut off from the rest of the body; and therefore the vegetative body is one continuous cavity. It is the one group of Fungi that can be recognized from its mycelium. The sexual apparatus very much resembles that of the Algæ, and the whole structure of the body is so suggestive of Algæ that if these were the only Fungi probably no one would doubt that Fungi had been derived from Algæ. On account of this resemblance, the group is called the "Alga-fungi" (*Phycomycetes*). Among the illustrations used above, the molds and downy mildews are members of this group.

Fig. 43. — Puffballs. — After Gibson.

In the second group the mycelium has cross walls, but the sex-apparatus, so far as any has been found, is not very suggestive of the Algæ. The distinguishing mark of the group, however, is the production of spores within a sac that has a peculiar origin. Therefore the group is called the "Sac-fungi" (*Ascomycetes*), and the lilac mildew, mentioned above, is a member of it. In that plant the spore-containing sac (*ascus*) is inclosed, usually along with others, by a case (Fig. 34), but in many Sac-fungi the case does not inclose the sacs, but forms disks, cups, funnels, or flasks, which the sacs line. Any fungus in whose life-history these sacs appear is a "Sac-fungus."

In the third group the mycelium has cross walls, as in the

second, but the spores are formed at the ends of slender branches that arise from a peculiar cell or group of cells

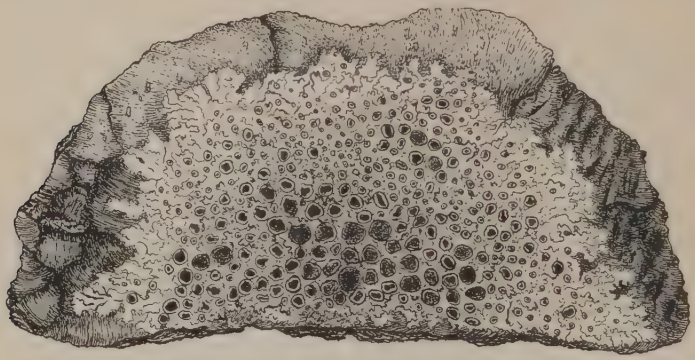


FIG. 44. — A lichen growing on bark; the numerous dark disks are cup-like spore-cases.

called the *basidium* (Fig. 41). These are therefore the "Basidium-fungi" (*Basidiomycetes*), and the wheat rust and

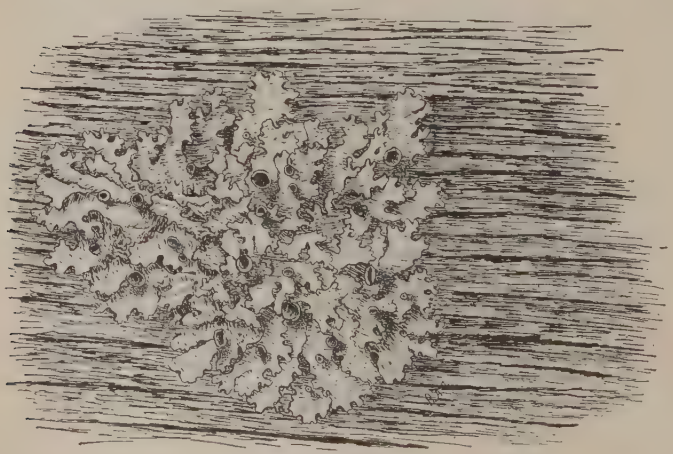


FIG. 45. — A lichen growing on a board.

mushrooms are members of it. Any fungus in whose life-history basidia appear is a "Basidium-fungus."

Perhaps the best definition of the first group (Phycomycetes) is that it includes all true Fungi in whose life-histories neither asci nor basidia appear.

39. **Lichens.** — Lichens are very commonly observed plants, forming splotches of various colors on tree trunks, rocks, old boards, etc., and growing also upon the ground. They may resemble incrustations on these various supports; or they may have very definite flat and lobed bodies that are not attached throughout to their supports (Figs. 44 and 45); or they may have slender, branching bodies that are erect, hanging, or prostrate. The so-called "reindeer moss" is an erect, branching lichen common in northern latitudes; and in certain mountain regions trees are frequently thickly covered with the hanging lichens (Fig. 46).

FIG. 46. — A hanging and profusely branching lichen. — After SACHS.

The most important fact about a lichen is that it is made up of two very different plants, a fungus and an alga; but these two are so closely associated that they seem to belong to a single body (Fig. 47). In fact, a lichen is a parasitic fungus that obtains its food-supply from certain Algæ, and in doing so inwraps the Algæ completely. Apparently the Algæ are not injured, and in fact their position in the midst of a moist, sponge-like body is very favorable for their work.

This means that in this position the Algæ manufacture food enough for themselves and for the fungus, for otherwise they would be destroyed.

This association has led to some very important results. It makes it possible for the two plants to exist in conditions that would be impossible for either plant alone. For example, lichens are abundant on bare rocks, from which all other plants are absent. In ascending mountains, after all other vegetation has disappeared, the lichens persist on the most exposed rocks. In such places the alga could not grow alone because of lack of moisture, and the fungus could not grow alone because of lack of food; but in the sponge-like body of the fungus the alga gets its moisture, and from the enmeshed alga the fungus gets its food. This fact is important, because lichens can thus start soil-formation on bare and exposed surfaces. The materials of their dead bodies give to other plants a chance to grow, and so a soil gradually accumulates.

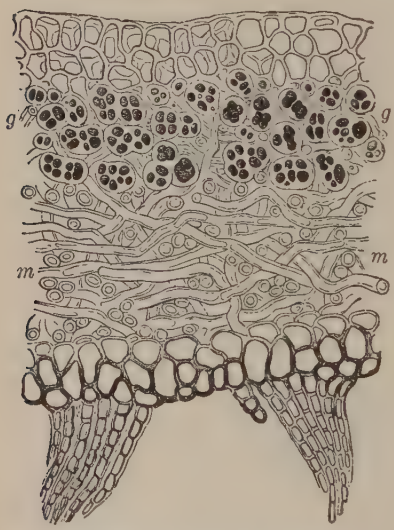


FIG. 47. — Section of a lichen, showing the interwoven mycelium of the fungus (*m*) and the enmeshed alga (*g*). — After SACHS.

At certain times disk-like or cup-like bodies are borne by lichens, with brown or black or more brightly colored lining (Figs. 44 and 45). When this lining is examined, it is found to be made up largely of delicate sacs containing spores (Fig. 48). This shows that the lichen fungus is a sac-fungus

(Ascomycete), and that a lichen is simply a sac-fungus parasitic on Algæ. With very few exceptions, all lichens are Sac-fungi.

40. **Soil Fungi.** — Before leaving the Fungi, further reference should be made to the part they play in the soil. The work of bacteria in the soil was referred to in a preceding section (§ 37, p. 46), but true Fungi are important also.

The soil must not be thought of as simply an accumulation of " dirt," but as material very full of life. Just as the waters

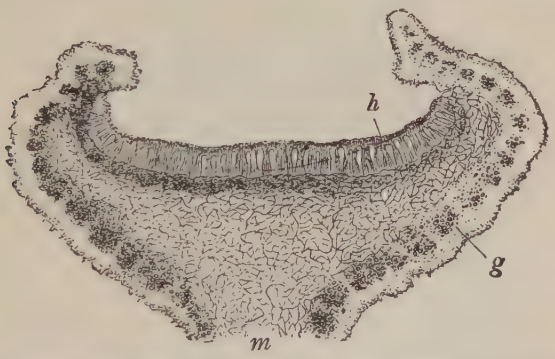


FIG. 48. — Section of the cup-like spore-case of a lichen, showing the lining layer of sacs containing spores (*h*); the tangle of the mycelium (*m*) and the groups of Algæ (*g*) may be seen. — After SACHS.

are spoken of as " swarming with life," so are the soils " swarming with life," chiefly Fungi. What makes this fact important is that the soil Fungi are important factors in making the soil suitable for plants. The nature of the work accomplished by these soil Fungi, in relation to the use of soil by plants, may be outlined as follows.

In speaking of the manufacture of proteins (§ 29, p. 37), the statement was made that in connection with this process compounds containing nitrogen must enter the plant. In the case of soil plants, these compounds are obtained from the

soil in the form of salts called nitrates, which are soluble and therefore "available." It is evident that when crops are

FIG. 49. — Root-tubercles on sweet clover.

removed from the soil, a large amount of nitrogen compounds is removed also, so that crops drain nitrogen from the soil. This cannot go on indefinitely, without fresh supplies of

nitrogen for protein manufacture. This is what is often meant when a soil is said to be " impoverished."

There are at least two general ways by which fresh supplies of available nitrogen are being added to the soil continuously, and the agents in both cases are bacteria. One way is to obtain nitrates (nitrogen in its available form for plants) from the decay of organic matter, and whole series of bacteria are active in the various steps of this process. Therefore, as bodies of plants and animals die, or leaves and branches fall, or manure is spread on the soil, relays of bacteria lay hold of this material, and among the products of their activity are the nitrates.

The other way is to use the free nitrogen of the air in the manufacture of nitrates, and certain bacteria are the agents in this remarkable process. It is an interesting fact that although the air is about four-fifths free nitrogen, and that plants are therefore living submerged in an ocean of nitrogen, they cannot use it in this free form, that is, it is not available. But the soil bacteria referred to are very exceptional among plants in the power to use free nitrogen (soil water contains free nitrogen in solution), probably in the manufacture of their proteins. This work results in more organic material containing nitrogen to become the source of nitrates. These " nitrogen-fixing " bacteria, as they are called, work conspicuously in connection with the clovers, alfalfa, etc., on whose roots they form little swellings (" tubercles," Fig. 49), and from which they obtain carbohydrate food. The clovers in turn consume the bacteria, and if the clover crop is plowed under (" green manuring "), a large amount of nitrogen-containing material is added to the soil, whose nitrogen came from the air by way of the nitrogen-fixing bacteria.

These two kinds of work partially explain why the soil improves when a field " lies fallow " (is not used), and why it is of advantage to alternate a clover or alfalfa crop with other kinds of crops (" rotation of crops "). In the former

case, the loss of nitrogen is stopped and nitrates are allowed to accumulate; in the latter case, fresh drafts on the air, the ultimate source of nitrogen, are made. There are other reasons why a soil improves by "resting" or by a clover crop, but these will be referred to when the crop plants are studied. In this connection we are merely concerned with the work of Fungi in the soil.

The true Fungi of the soil, with their network of filaments extending everywhere through the soil, have proved to be of much greater importance than was once supposed. These subterranean mycelia become connected with the roots of many plants (Fig. 50), from which they obtain their food-supply, and in so doing put at the service of the host plant an extensive water-receiving and salt-receiving system. Such plants as orchids and oaks have long been notorious for using subterranean mycelia in this way, but it is found now that this arrangement is of great advantage to any plant. Especially does this habit prevail in forest soil, which is "a living mass of innumerable filamentous Fungi." In effect, this connection established between an oak, for example, and the subterranean mycelia, resembles the establishment of a connection between the pipe systems of a house and those of a city. With such a connection, soil water and soil salts far beyond the reach of the root system of a plant become available. Such Fungi are called *mycorhiza*, a name meaning "root-fungi."

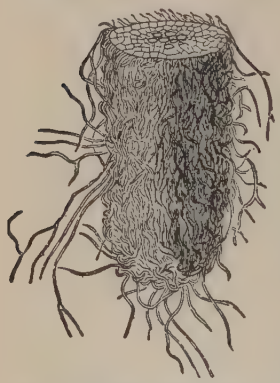


FIG. 50. — Mycorhiza: the tip of a beech rootlet enmeshed by a soil fungus. — After FRANK.

41. **Summary.** — The Fungi are Thallophytes that cannot manufacture food, and therefore are dependent plants. The dependent habit compels them to obtain food as

parasites or saprophytes, and therefore they are of great economic importance. They may be very useful, as are the soil Fungi, or they may be very injurious, as are the disease-producing Fungi.

The bodies of Fungi range from single cells (as the Bacteria) to filamentous bodies (the mycelia of true Fungi), and many of the higher forms become quite complex. The reproductive methods are also the same as those of Algæ; namely, vegetative multiplication, spore-reproduction, and sexual-reproduction with its differentiations. But among the higher Fungi the sexual-reproduction becomes less and less obvious, and in some cases it may have disappeared.

While the Algæ may be said to represent the foundation upon which the plant kingdom has been built, the Fungi hold no relation to the higher groups. In the history of the plant kingdom, therefore, the Algæ are much more important than the Fungi; but in the economic interests of man, the Fungi are much more important than the Algæ.

CHAPTER V

BRYOPHYTES

The First Land Plants

42. **Problem of the land habit.** — It was stated that Algæ live exposed to water as a medium, and that their structures and habits are explained by this fact. To live on the land means exposure to air as a medium, and the structures and habits of land plants are explained by this fact. The danger of exposure to air is the loss of water by the plant. It must lose water to the drying air, and unless there is some check, the loss will be greater than the supply, and death will ensue.

When an alga is removed from water and exposed to air, it dries out quickly and perishes, for there is no check to the very rapid loss of water from the protoplasts. Therefore, if water plants are to become land plants, they must acquire the air-habit by developing protective structures. It is believed that this is just what certain Algæ did, and that in so doing they became so different in structure that they ceased to be Algæ. In any event, the acquiring of the land-habit was about the most important happening in the history of plants, for it made possible all the subsequent progress of the plant kingdom.

One may picture how a gradually increasing exposure to air might have occurred, beginning with occasional exposures on muddy flats, and by gradual shoreward migration, ending in continual exposure. Even when exposure to air became continual, it must have been for a long time in conditions of

shade and moisture, for life "in the open" means extreme danger from loss of water.

43. **The Liverworts.** — This group of plants is not conspicuous, and therefore it is not noticed by most people, but it is believed to be the group that acquired the land-habit and that has given rise to all the higher plants. The Liverworts, therefore, are of very great historical importance, and should be known, by sight at least, to every student of plants. They may be called the amphibians of the plant kingdom, for they connect the water forms with the land forms.

Although Liverworts solved the problem of living on land, they give one the impression of being on the defensive against the air rather than of using the air and sunshine freely. For the most part, they occur in moist places, or at least in shaded places. It is one thing to live in protected places, and a very different thing to live and work in the open. To occupy the general land surface means that many plants must live in unprotected places, and it remained for the higher plants to solve this problem, by substituting protective structures and habits for protected places.

There are two general facts in this connection that should be kept in mind. One is that a plant may work in a protected place, but the opportunities for work are not so great. The progress of plants, therefore, implies that they must acquire the ability to use the largest opportunities. Another fact is that work and endurance are not the same thing. Plants may endure conditions of exposure, but not be able to work except so far as it is necessary to maintain life. An ordinary deciduous tree endures the winter, but it works in the summer. In considering the progress of plants, therefore, it is not a question of the conditions which they can endure, but of the conditions in which they can work.

44. **The body of Liverworts.** — If Liverworts are Algæ that have acquired the land-habit, it is important to know

something of the structure of the body that can resist the drying air. It is evident that an ordinary filamentous alga, with every cell freely exposed, could not endure long exposure to the air. But the bodies of certain Algæ are flat

FIG. 51. — *Riccia:* a group of floating Liverworts, showing the dorsal surface exposed to light; the flat body forks as it grows, and the axis of each branch is marked by a deep groove, in the bottom of which the sex-organs (antheridia and archegonia) occur. — Photograph by LAND.

plates of cells, and such bodies seem to have supplied the start for Liverworts. A brief description of a liverwort body will show how every fact is related to air exposure as contrasted with water exposure.

The body is compact; that is, the cells are close together,

forming a sheet of cells. In this way, only two sides of a cell are exposed, and if the sheet of cells is more than one layer thick, as is usual among Liverworts, the outside cells have one side exposed, and the cells within are not exposed at all.

The body lies flat, so that only the upper surface is exposed freely to the air (Fig. 51). This position, added to the fact that the body is usually lying upon a moist surface, results in the least possible amount of danger from exposure to the drying air. Since the liverwort body may be lying upon rock or soil or a tree trunk, it is convenient to have a general term to express the surface upon which it rests, and this term is *substratum*. The liverwort, therefore, is prostrate upon its substratum, and this position results in a *dorsiventral* body, which means that the body has two unlike surfaces, the *dorsal* and the *ventral*. In the liverwort, the dorsal surface is exposed to air and sunlight, while the ventral surface is in contact with the substratum. It is these two different kinds of exposure that result in the two surfaces being unlike. An ordinary leaf is a dorsiventral organ, with the two surfaces differently exposed and hence different in structure.

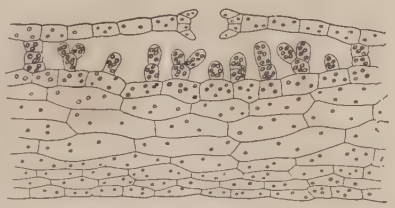


FIG. 52. — *Marchantia:* section through the body, showing the epidermis above and below (the upper and more exposed epidermal layer especially distinct), the air-chamber into which project special cells containing chloroplasts, the air-pore (with its chimney-like arrangement of cells) opening through the epidermis into the air-chamber, and the layers of comparatively colorless cells between the air-chamber and the lower epidermis.

When the liverwort body is several layers of cells thick, the outermost layer of cells is modified and becomes the protective layer known in all plants and animals as the *epidermis* (Fig. 52). The cells of the epidermis differ from the other cells of the body, and the differences make the

epidermis very resistant to the passage of water from the interior of the plant to the surface. In other words, the epidermis is in effect a waterproof layer, not to prevent water from entering the plant, but to prevent water from leaving the plant.

A compact, prostrate (dorsiventral) body, ensheathed by an epidermis, is well-equipped for exposure to the air, especially if the air is not very dry.

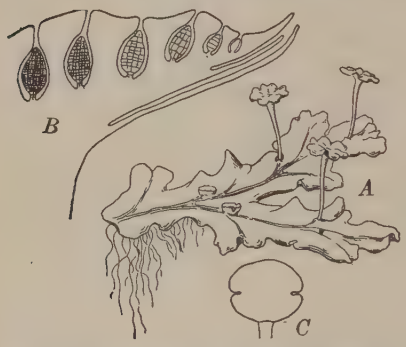


FIG. 53. — *Marchantia: A*, a plant bearing on its dorsal surface three long-stalked disks containing antheridia, and also two small cups containing gemmæ; the rhizoids arising from the ventral surface are also shown; *B*, a section through a part of one of the disks, showing the short-stalked antheridia in flask-shaped cavities that open on the upper surface of the disk; *C*, the outline of a gemma.

The dorsiventral position develops differences in different regions of the body. The dorsal side of the body is exposed to light, and as the light reaches the cells, chlorophyll is formed, and such cells are equipped for photosynthesis (Fig. 52). If the body is very thin, light may penetrate it completely, and all the cells will be green. But ordinarily the body is so thick that light of sufficient intensity does not penetrate through it, so that a certain number of layers of cells on the ventral side may not contain chlorophyll (Fig. 52). In this way the body is differentiated into two regions: a dorsal region of green cells doing the work of carbohydrate manufacture; and a ventral region of colorless cells. Another form of differentiation is seen in the structures produced by the two surfaces. The dorsal surface, with its free exposure to the air, develops the sex-organs and spores, for the spores are dispersed by currents of air (Figs. 53 and

54). The ventral surface puts out hair-like processes that grip the substratum (Figs. 53 and 54). These hairs are called *rhizoids,* which means "root-like," but they are not like roots. They have not the structure of roots, and they do not perform the work of roots except as they anchor the body.

This differentiation of the body, compelled by its position, outlines regions of work that become more definite in higher plants. Water enters the body through the lower epidermis, is conducted through the colorless cells on the ventral side, is brought to the green cells on the dorsal side, and is partly used there in food manufacture. It must not be supposed that all of the water that enters a plant is used in photosynthesis, for the bulk of it keeps the protoplasts of all the cells in a condition for working, and the protoplasts are losing it all the time to the air. The problem of the plant is to see to it that the protoplasts do not lose water faster than it is supplied. The picture in one's mind, therefore, should be that of a stream of water moving continuously through the body of the plant, primarily to keep it in working condition, and incidentally to supply a little for photosynthesis.

FIG. 54. — *Marchantia:* a plant bearing on its dorsal surface three long-stalked disks with finger-like lobes and containing archegonia, and also two small cups containing gemmæ; the archegonia are found on the ventral side of the disk, hanging from the angles between the lobes.

The epidermis introduced a new problem which the Liverworts and all the higher green plants have solved. In order to do their peculiar work, the green cells must be exposed to the air, from which carbon dioxide is obtained, and to which

oxygen is given. The waterproofing epidermis interferes with this exchange, and therefore it must be interrupted enough to let the air into the green cells. In the simpler Liverworts these openings for the air are secured by clefts, while in complex Liverworts there are elaborate *pores* in the epidermis, that open into internal air chambers (Fig. 52). In this latter case there is an internal atmosphere that bathes the green cells, which communicates with the external atmosphere through the pores. In this way the gas exchange is provided for; but the pores also open up a way for the escape of water vapor from the inner cells. This loss of water is the price the plant must pay for the opportunity to manufacture food.

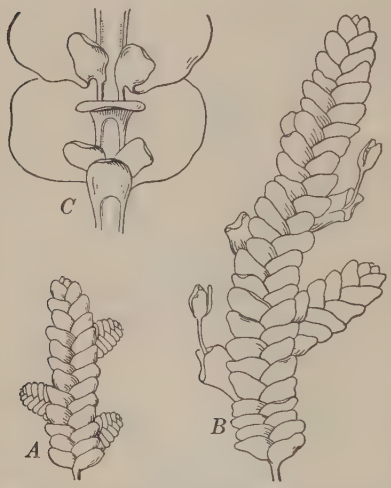


FIG. 55. — *Porella*, a leafy liverwort: *A*, a plant showing the two rows of overlapping dorsal leaves, and also three special branches that bear antheridia; *B*, a plant with the special branches that bear archegonia (two of these branches are bearing the spore-cases produced by the fertilized egg); *C*, ventral view of a plant, showing the ventral leaves much modified by being in contact with the substratum.

The bodies of Liverworts have advanced in two general directions. Some Liverworts have retained the primitive form of the body, a continuous sheet of cells which branches by forking, and have advanced in making the structure of the body more and more complex (Fig. 51). Other Liverworts, and these are far more numerous, have retained the simple structure of the body, and have advanced in changing the form of the body, so that the flat sheet becomes differentiated into a central axis (stem) bearing many lobes of

green tissue (leaves). These are the so-called "leafy Liverworts," and they are the representative Liverworts of to-day, in the sense that they are the most numerous (Fig. 55). They look so much like delicate mosses, for which most people mistake them, that they are also called "scale mosses," the leaves looking like small scales rather than ordinary leaves. The two directions of differentiation of the liverwort body, therefore, are (1) from simple to complex in *structure*, and (2) from simple to complex in *form*.

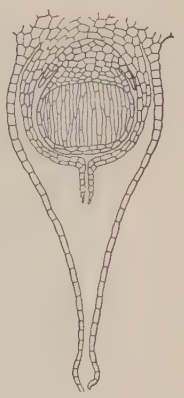


Fig. 56. — *Marchantia*: a spore-case (sporophyte) formed by the fertilized egg of an archegonium; notice the two regions of the sporophyte, the spore-bearing region, and above it the sterile region embedded in the disk above by an anchor-like growth (the foot).

45. **Reproduction of Liverworts.** — The three methods of reproduction developed by the Algæ are continued among Liverworts, and the differences to be noted have resulted from exposure to air.

A common method of vegetative multiplication is by the isolation of branches. When the body of a liverwort forks, so that there are two branches, the old body may die up to the fork, and the two branches become two separate individuals. As bodies continue to fork and to die behind, an indefinite series of individuals may be formed in this way.

Some Liverworts form special structures that may be called reproductive buds, that are separated from the parent body and produce new individuals. These buds usually grow out from the dorsal surface, and since some of them are notched on opposite sides so as to have a paired appearance, they have been called *gemmæ* (Fig. 53, *C*).

By the isolation of branches and by gemmæ the bodies of Liverworts may be multiplied extensively, without any other form of reproduction.

There is also reproduction by spores, and these spores differ from those of the ordinary Green Algæ in that they do not swim, but are dispersed by the air. This means that they are light and have a protecting wall against drying out. Furthermore, they are produced in a special spore-case (Figs. 55, *B*, and 56), whose formation is described below.

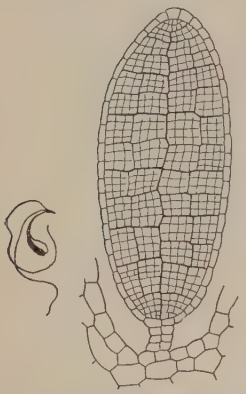


Fig. 57. — *Marchantia:* an antheridium, showing the short stalk, the single layer of cells forming the jacket or wall, and the blocks of cubical cells that produce the swimming sperms; a sperm is also shown with its two long cilia.

There are also sex-organs that produce sperms and eggs, and they also show changes that fit them for exposure to air. The cells that produce the sperms and eggs are invested by a jacket of cells, and therefore the sex-organs of Liverworts appear to be much more complex than those of the Green Algæ. The sex-organs are produced on the dorsal surface of the liverwort body, in some forms well distributed over the surface, and in other forms restricted to certain small areas. When they are restricted, the small area of the body on which a group of sex-organs occurs may become distinct enough from the res of the body to be called a *disk*, and in some cases this disk may be carried up from the rest of the body by a stalk, which may become very long for the size of the body. The two kinds of sex-organs do not occur in the same disk, and in some forms there is only one kind of disk on the body, resulting in male and female plants (Figs. 53 and 54).

The antheridium is a globular or ovoid body (Fig. 57), with a short or long stalk, and consists of a layer of jacket cells (forming the wall of the antheridium) investing a mass of small cubical cells that produce sperms. The sperms are very small cells with two cilia, so that they are equipped for

swimming (Fig. 57). It is an interesting fact that the spores became related promptly to air dispersal, but that the sperms retained the water habit of swimming. This means that the act of fertilization can take place only in the presence of water, so that if a liverwort is kept from free water, fertilization does not occur. It must be remembered, however, that even " a film of dew " is sufficient water for the swimming of such sperms.

Among the Algæ, the female sex-organ was called an oögonium, but among the Liverworts and all higher plants it is called an *archegonium*. It is so constant in appearance that it is recognized easily in any group in which it occurs (Fig. 58). The protective jacket forms a flask with a more or less slender neck, and in the body of the flask the egg is formed. The two regions of an archegonium, therefore, are the *neck*, through which the sperms pass to reach the egg, and the *venter* (the body of the flask) in which the egg lies.

FIG. 58. — *Marchantia:* an archegonium, showing the long neck, and the venter containing the egg.

When the water conditions are favorable, the sperms swim to the archegonia, enter the necks, reach the eggs, and fuse with them, and the result is a fertilized egg (oöspore) in each archegonium.

46. **Alternation of generations.** — A most important fact in connection with Liverworts remains to be told. Among the ordinary Algæ, the fertilized egg, just as the spore, produces a plant like that from which it came, so that the life-history formula (§ 17, p. 24) is $P \overset{\circ}{\underset{\circ}{\square}} > o — P$. But when the fertilized egg of a liverwort germinates, it produces a very different kind of plant. This new kind of individual is a spore-case, which in most Liverworts has a stalk, and the

stalk may be very long. This spore-case individual is usually without chloroplasts, so that it cannot manufacture food. It obtains food from the plant that produced the egg, usually by the end of its stalk becoming imbedded in the tissue of that plant. This imbedded part of the stalk often becomes enlarged and is called the *foot*, and it is through the foot that food enters the spore-case individual, which is therefore a parasite.

When the spores formed by this individual germinate, they do not produce other spore-case individuals, but they produce the green liverwort body.

The life-history of a liverwort, therefore, includes two individuals that alternate with one another. One individual is green and bears the sex-organs (containing gametes), and hence is called the *gametophyte* (" gamete-plant "); the other is a parasite and produces spores, and hence is called the *sporophyte* (" spore-plant "). The fertilized egg of the gametophyte produces the sporophyte, and the spore of the sporophyte in turn produces the gametophyte. The life-history formula, using G for gametophyte and S for sporophyte, thus becomes $G \overset{o}{\underset{o}{=}} > o—S—o—G \overset{o}{\underset{o}{=}} > o—S$, etc. This is *alternation of generations*, meaning that two individuals (generations) alternate in the life-history. This is a most important fact in connection with Liverworts, because all of the higher plants continue this alternation, and their advance has depended upon the modification of these two generations. It must not be supposed that Liverworts *introduced* alternation of generations, for it was started among Algæ, but Liverworts *established* it, and all plants afterwards retained it.

It will be noticed that alternation of generations involves a division of labor. Among Algæ that do not possess it, the same individual manufactures food, produces spores, and forms gametes. In Liverworts, the gametophyte manufactures food and forms gametes, while the sporophyte

produces spores. The gametophyte is the more conspicuous generation on account of food manufacture, which demands a display of green tissue, and therefore among Liverworts the gametophyte is thought of usually as " the plant," and the sporophyte as its " fruit." Of course the sporophyte is in no sense a " fruit," for it has no more connection with the gametophyte than a parasite has with its host.

Since gametophytes and sporophytes will be changing in appearance and relative prominence as we proceed through the higher groups, it is well to begin with a sure rule for recognizing them. Whatever a fertilized egg produces, no matter what it looks like, is a sporophyte; and whatever a spore produces, no matter what it looks like, is a gametophyte. If this rule is remembered, the two generations will be recognized in spite of all their disguises.

47. **The Mosses.** — The Mosses are much more abundant now than the Liverworts, and are able to live in much more exposed places. In fact, Mosses are associated with Lichens in the ability to live in conditions that are impossible for other plants. That ancient Liverworts were the ancestors of Mosses is generally believed, and the first question is as to the differences that distinguish Mosses from Liverworts.

Fig. 59. — The leafy gametophore (leafy branch) of a moss rising as a branch from the prostrate filamentous body.

It will be remembered that in some Liverworts the disk bearing the sex-organs is lifted up from the rest of the body by a long stalk (Figs. 53 and 54). Since this stalk bears the sex-organs (which contain the gametes), it is called a *gametophore* ("gamete-bearer"). In the Mosses this gametophore always appears, but instead of being a naked stalk, as in Liverworts, it is covered with numerous small leaves (Fig. 59).

The distinguishing mark of a moss, therefore, is the leafy gametophore. It is these leafy and usually branching gametophores that people in general think of as the "moss plant," for they are the most conspicuous part of it. It is evident that green tissue in the form of leaves on a gametophore is in a much better position in reference to air and sunlight than green tissue prostrate on some sub-

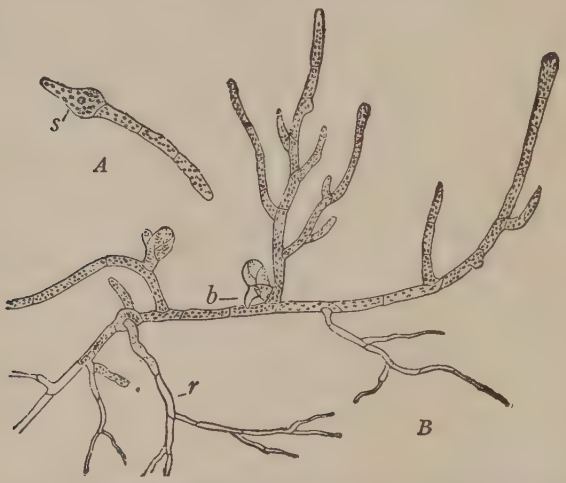


FIG. 60. — The filamentous body of a young moss plant: *A*, the filament starting from the spore (*s*); *B*, the older filament, showing the branching habit, rhizoids (*r*), and a bud (*b*) which is to develop a leafy gametophore. — After MUELLER-THURGAU.

stratum, as in the Liverworts. Since the leafy gametophore is only a vertical branch from the prostrate body, it is often called the *leafy shoot.*

In most Mosses the prostrate (dorsiventral) body does not develop like those of Liverworts, but instead of being a flat sheet of cells, it is a green, branching filament, resembling a green, filamentous Alga (Fig. 60). It is important to know that when the liverwort body is developing it passes through a filamentous stage before it becomes a sheet of cells. This means that the filamentous body of the moss is not a

different kind of body, but resembles a liverwort body that has not fully developed. This failure of most Mosses to develop bodies to the mature liverwort stage is probably associated with the fact that the gametophore bears leaves and the chief work of food manufacture is done no longer by the prostrate body.

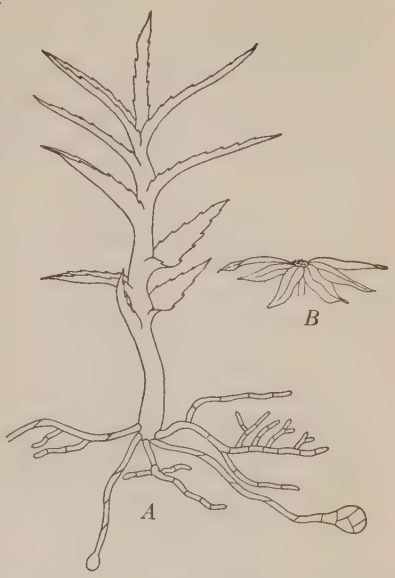


FIG. 61. — *A*, a leafy branch (gametophore) that has become independent by putting out its own rhizoids; *B*, a rosette of leaves surrounding a group of sex-organs (forming the so-called "moss flower").

The picture of a moss, therefore, is a delicate, prostrate, branching, green filament (which most people do not see), from which arise numerous vertical leafy branches (which most people regard as the whole plant), and since these leafy branches are gametophores, they bear the sex-organs.

There is some excuse for regarding the branching gametophore as the whole plant, for it sends out its own rhizoids into the substratum, the delicate green filament from which it arose dies, and the gametophore becomes completely independent (Fig. 61). In addition to this, the gametophore can reproduce extensively by vegetative multiplication, so that masses and "beds" of moss are formed. In fact, most

FIG. 62. — Tips of leafy branches of a moss, one of them bearing a group of sex-organs surrounded by a rosette of modified leaves.

of our experience with Mosses is their occurrence in sheets and beds.

48. **The sex-organs.** — It is evident that the prostrate filamentous body of a moss with its leafy gametophore branch is the gametophyte generation. The antheridia and arche-

FIG. 63. — Sex-organs of a moss: *A*, an antheridium discharging sperms, one of which is shown (*c*); *B*, section of a group of archegonia invested by leaves; *C*, an archegonium, with its long neck, and its venter containing an egg. — After SACHS.

gonia have the same general structure as do those of Liverworts (Fig. 63), and are borne in clusters at the tips of branches or of the main axis (Fig. 62). The leaves about these terminal clusters often become close set, forming a rosette, and they may differ in appearance (size or color) from the other

leaves (Figs. 61, *B*, and 62). These rosettes of leaves inclosing sex-organs have been called moss "flowers," but they hold no relation to real flowers. In a single one of these moss rosettes both kinds of sex-organs (antheridia and archegonia) may occur, or only one kind (Fig. 63, *B*). In the latter case, therefore, there are male rosettes and female rosettes; and if such rosettes occur on different plants, there are male plants and female plants.

Fig. 64. — Two moss plants (leafy gametophytes) bearing mature and long-stalked sporophytes; the spore-case on the left is still covered by the cap (calyptra) formed by the archegonium; the spore-case on the right shows the lid which drops off and exposes the spores.

49. **The sporophyte.** — The sporophyte of a moss is much more elaborate than that of a liverwort. Usually it is long-stalked, the capsule (spore-case) opens by a lid, the spore-bearing region is small compared with the rest of the sporophyte, and the whole structure is very complex (Figs. 64 and 65); but it still lives as a parasite on the gametophyte, and is commonly (and wrongly) called the "fruit" of the moss.

50. **Evolution of the sporophyte.** — After the establishment of alternation of generations by Liverworts, the most important fact in connection with Bryophytes (Liverworts and Mosses) is the progress made by the sporophyte, which is usually spoken of as its "evolution." It was upon the sporophyte that the whole future of the plant kingdom depended, for it is the structure of the sporophyte that determines the higher groups.

First stage of the sporophyte. — The simplest sporophytes among the Liverworts are merely spore-cases, consisting of a jacket of sterile cells (cells that do not produce spores)

investing a mass of spore-producing cells (Fig. 66, *A*). There is no stalk, and there are no sterile cells except the single layer forming the jacket. When the sporophyte gets to be very complex, it is important to remember that the oldest tissue in it (historically) is that which produces spores (sporogenous tissue), for this will clear up many false impressions.

Progressive changes. — The conspicuous change observed in certain other Liverworts is that the cells inclosed by the sterile jacket do not all produce spores. For example, in some forms one-half of the inclosed tissue produces spores and the other half remains sterile (Fig. 66, *B*). This sterile tissue forms a short stalk, and so different regions of the body begin.

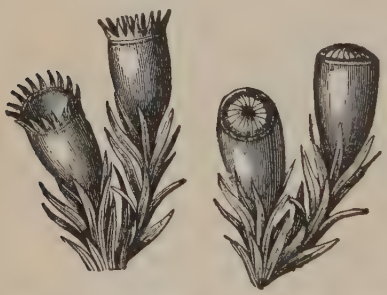


FIG. 65. — Spore-cases of a moss from which the lids have fallen, showing the teeth. — After KERNER.

In other forms, still more tissue remains sterile, which means that the sporogenous tissue becomes relatively less in amount (Fig. 66, *C*). With the increase of sterile tissue, the stalk and the capsule become more complex (Fig. 66, *D*); until in the higher Mosses almost the whole complex sporophyte is sterile, and the sporogenous tissue is not only relatively small in amount, but appears late in the development of the sporophyte (Fig. 66, *E*). The sporogenous tissue which in the beginning was the first and only tissue (except the sterile jacket), becomes finally in the higher Bryophytes the latest and most inconspicuous part of the sporophyte. It is the ever increasing sterile tissue that the higher plants use in carrying the sporophyte to still more advanced stages.

Anthoceros. — Among the Liverworts there is a group of which *Anthoceros* may be used as a representative. The body is a prostrate sheet of cells, sometimes lobed but not leafy, and resembles the bodies of many Liverworts (Fig. 67). It is not complex either in structure or in form, but it has a remarkable sporophyte. It is believed by many that this represents the kind of liverwort sporophyte that gave rise

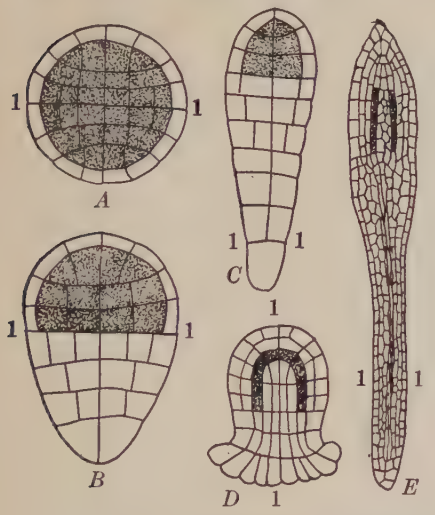


FIG. 66. — Diagrams illustrating the evolution of the sporophyte among Bryophytes: *A*, sporophyte of *Riccia*, being only a spore-case; *B*, sporophyte of *Marchantia*, showing a reduced amount of sporogenous tissue, and the sterile cells forming a short stalk; *C*, sporophyte of a leafy Liverwort, showing further reduction of sporogenous tissue and corresponding increase of sterile (stalk-forming) tissue; *D*, sporophyte of *Anthoceros*, showing further decrease of sporogenous tissue and increasing complexity of capsule and stalk (including foot); *E*, sporophyte of a Moss, showing extreme reduction of sporogenous tissue and great complexity of capsule and stalk; the numerals (1–1) indicate the first wall of the dividing egg (note that in *A* and *B* the two halves of the egg contribute almost equally to the sporophyte; that in *C* one-half of the egg produces the sporophyte; that in *D* the first wall is vertical; and that in *E* almost all the sporophyte is produced by one-half of the egg.

FIG. 67. — *Anthoceros:* the prostrate body bearing long and narrow sporophytes; the two sporophytes to the left are mature and have split to discharge the spores.

to the higher groups of plants. If this is true, such a sporophyte deserves special attention.

Throughout the Bryophytes (Liverworts and Mosses),

the sporophyte is dependent upon the gametophyte, and is never an independent plant. In the higher groups (Fern-plants and Seed-plants) the sporophyte is an independent leafy plant. In some way, the dependent, leafless sporophyte of Bryophytes becomes the independent, leafy sporophyte of Pteridophytes (Fern-plants), and the liverwort *Anthoceros* has a sporophyte that has suggested the way. Just as Liverworts are more important than Mosses in the history of the plant kingdom, so are the *Anthoceros* forms the most important Liverworts in the history, although they are the least abundant.

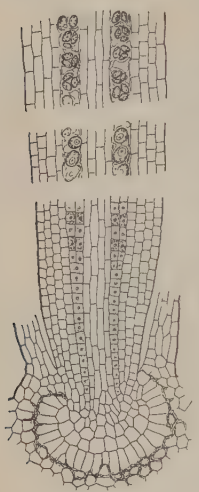


FIG. 68. — *Anthoceros:* longitudinal section through the sporophyte (broken into three regions), showing the bulbous foot imbedded in the gametophyte, and the three regions of the sporophyte above: (1) the green region (four layers of cells), (2) the spore-producing region (the stages in spore-formation may be observed by tracing this region from below upwards), and (3) a central region.

From what has been said, it is evident that any sporophyte of the Bryophytes that shows a tendency to become independent is on the way towards an independent sporophyte, and when complete independence is attained the sporophyte no longer belongs to Bryophytes. The peculiarity of the *Anthoceros* sporophyte is that it is more nearly independent than the sporophyte of any other bryophyte. This sporophyte does not consist of a roundish spore-case on a more or less elongated stalk, as in other Liverworts and in the Mosses, but elongates without a stalk, until it resembles a small grass-blade (Fig. 67). The most striking fact, however, is not its form, but that it is as green as a grass-blade. The presence of chloroplasts means that this sporophyte is able to manufacture food, and although it has a bulbous foot sunk in the thin body of the gametophyte (Fig. 68), it does not

obtain all its food from the gametophyte. If such a sporophyte should establish connections with the soil (on which the gametophyte is lying) by means of roots, it would become an independent plant, and no longer be a bryophyte.

Although the sporophyte of *Anthoceros* has been likened to a small grass-blade in form and color, it is very far from having the structure of a grass-blade, for it is in no sense a leaf. It is a stem-like structure, which has the power of elongating like a stem, and a section across it shows three regions (Figs. 68 and 69); (1) a green region on the outside, (2) a spore-producing region next to the green, and (3) a central region of colorless and sterile cells. This is the structure which is thought to have given rise to sporophytes with stems and leaves.

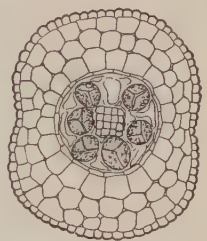


FIG. 69. — *Anthoceros:* cross-section of a sporophyte, showing the three regions described under Fig. 68; the very distinct surface layer of cells is the epidermis.

51. **The failure of Bryophytes.** — This does not mean that Bryophytes are failures in themselves, for it has been seen that they are abundant enough to be called successful. The failure referred to is that the bryophyte plan could not make any further progress leading to higher plants. We infer that this is true, simply because the plan of the higher plants is different.

A gametophore is developed by many Liverworts and by all Mosses. As the name implies, this stalk carries up the gametes (eggs and sperms) above the general surface of the prostrate body. Since the fertilized egg produces the sporophyte with its spore-case, the gametophore certainly puts the spores in a favorable position for dispersal by air. If this position favors the spores, however, it does not favor the sperms which must swim, for they are carried up into a position of least moisture. It is an interesting arrangement that favors spores by interfering with the very act (fertiliza-

tion) that results in spores; but it works reasonably well for plants living in moist situations.

The Mosses use the upright gametophore for the display of green tissue, and it becomes leafy; but the larger and more exposed the gametophores of Mosses become, the more unlikely it is that fertilization can occur. It is evident that still larger and more leafy plants would interfere with the swimming of sperms still more.

The three things that enter into this problem are food manufacture (which means display of green tissue to light and air), fertilization (which means water for swimming), and spore-production (which means exposure for air-dispersal). In the Bryophytes, food manufacture and fertilization belong to the gametophyte, and the condition that favors one hinders the other. In other words, they are contradictory in their demands. On the other hand, food manufacture and spore-dispersal make the same demands for exposure, and therefore they can be coupled together to advantage. The further progress of plants, therefore, demanded that the spore-producing generation (sporophyte) should also become the food-manufacturing generation; and that the gametophyte, with its peculiar need for free water, should be restricted to fertilization. In the higher plants (Fern-plants and Seed-plants), therefore, the sporophyte is the conspicuous, leafy, independent generation, and the gametophyte is so very inconspicuous that it is only seen by those who know where and how to look.

52. **Summary.** — The contribution of the Bryophytes to the progress of the plant kingdom is notable. Of first importance is the establishment of the land habit by green plants (Liverworts), which means exposure to air rather than to water. This made possible the further development of plants on the land surface. In consequence of this change in conditions of living, the plant bodies are much more compact, and develop protective structures against excessive

loss of water by evaporation. Not only are the working bodies protected, but the sexual-cells are jacketed, so that the sex-organs (antheridium and archegonium) are many-celled.

The most significant result of the land habit was the establishment of an alternation of generations, so that sporophyte and gametophyte alternate regularly in the life-history. Among Bryophytes the gametophyte is the conspicuous generation, because it manufactures food in addition to producing sex-organs, and the sporophyte is dependent upon it. In one group of Bryophytes (*Anthoceros*) the sporophyte is green, so that the possibility of an independent sporophyte is evident.

The further progress of the plant kingdom is dependent upon an independent sporophyte, because the free display of green tissue by a gametophyte means conditions unfavorable for the swimming of sperms necessary to fertilization, while the free display of green tissue by a sporophyte means conditions favorable also for the dispersal of spores.

CHAPTER VI

PTERIDOPHYTES

The First Vascular Plants

53. **Recapitulation.** — The history of the plant kingdom has been followed from the Algæ, exposed to water, to the Liverworts, exposed to air. From the Algæ the dependent Fungi seem to have come, and together the two groups constitute the Thallophytes, the lowest great division of plants. From the Algæ the Liverworts also came by acquiring the land habit, and in turn gave rise to Mosses, and Liverworts and Mosses together constitute the Bryophytes, the second great division of plants. In the Bryophytes the body is more complex than in the Thallophytes, is related to air exposure, and alternation of generations is established. In this alternation the gametophyte is the independent generation, displaying the green tissue and bearing the sex-organs; and the sporophyte is a dependent generation. In such Liverworts as *Anthoceros*, however, the dependent sporophyte has advanced far towards independence, as shown by its development of abundant green tissue, which makes the sporophyte only partially dependent. Therefore, it seems probable that the Liverworts gave rise not only to the Mosses, but also to the third great division of plants (Pteridophytes), with its completely independent sporophyte. It is important, therefore, to examine the structure of the independent sporophyte, for it involves much more than the appearance of green tissue.

54. **The vascular system.** — In all independent sporophytes there develops a tissue which does not appear in the dependent sporophytes of Bryophytes. It is called *vascular tissue*, which means a tissue composed of vessels. The so-called vessels are thick-walled, tubular cells that extend through the sporophyte and are equipped to conduct water. The vascular tissue does more than conduct water, but its other work will be considered later. Of course water is conducted through the bodies of Liverworts and Mosses, but the vascular tissue conducts it with more rapidity and precision than any other tissue. The difference between water-conduction in a liverwort and in a plant with vascular tissue may be likened to the difference between water working its way through a swamp and water moving in definite channels.

It must not be supposed that the water-conducting vessels are continuously open tubes, as are the arteries and veins of the human body or the water pipes of a house. They are elongated cells set end to end, so that water in moving through the tissue must pass through numerous cell-walls, thousands of them in an ordinary stem. How water moves under these conditions is not known with certainty, but the direction of its movement is clear.

The vascular tissue does not extend at random through the body of the sporophyte, but has a definite organization, so that there is a *vascular system* in every sporophyte. The vascular system has proved to be of very great service in the study of the relationships of vascular plants, for it differs in the various great groups. That part of the vascular tissue which conducts water is called the *xylem*, which means "wood," for the ordinary wood of trees is xylem tissue.

55. **The leaf.** — In addition to a vascular system, the independent sporophyte has leaves. Leaves are simply expansions of green tissue that increase the amount of green tissue exposed, and so increase the capacity of the plant for

food-manufacture. It must not be supposed that leaves do all the work of food-manufacture, for it is done by any green part of the plant; but leaves do the most of it because they display the most green tissue.

The leaves of leafy Liverworts and of Mosses have been spoken of, but those leaves belong to the gametophyte. It

FIG. 70. — Portion of the leaf of a maidenhair fern (*Adiantum*), showing the forking veins.

is in vascular plants that one meets the first sporophyte leaves; and they are very different in structure from gametophyte leaves.

An important fact to observe in connection with the leaves of vascular plants is that they are not merely expansions of green tissue, but that through the green tissue there extend "veins" (Fig. 70). These so-called veins are extensions of the vascular system into the leaf, for the xylem carries water

to the working cells. Leaves differ in the arrangement of their veins, but every arrangement means an effective distribution of water to the working cells. There are main veins (often only one) that give rise to smaller ones, and these in turn to still smaller ones, until the system of veins forms a complete network through the green tissue (Fig. 155). The system may be likened to the water-pipe system of a house, with its main pipe, which gives off smaller pipes, and these in turn still smaller ones, until every room in a large house may be supplied with water.

The vein system of a leaf, in addition to carrying water, incidentally forms a stiff framework with its woody fibers, which helps to support the delicate green tissue and keep it from collapsing.

FIG. 71. — Branch of a club-moss (*Selaginella*), showing the numerous simple leaves; the leaves at the tips of the branches bear sporangia, and therefore are sporophylls, so that each branch-tip in this case is a strobilus.

It is known to every one that leaves are extremely variable in size and form. For example, among the Pteridophytes, the first great group of vascular plants, they are very small in the Club-mosses (Fig. 71), and are often very large among the Ferns (Fig. 72). Also in the Club-mosses the whole leaf is a single small blade

(as the green expansion is called), while in many Ferns the large leaf may be broken up into many blades (Figs. 70 and 72).

Since the largest amount of working tissue is exposed to the air by leaves, it follows that the leaves lose most water.

FIG. 72. — Shield ferns (*Aspidium*), showing the large leaves broken into many blades.

They must be kept full of water and they must be exposed to the air, so that great loss is inevitable, and the vascular system must make it good. The escape of water from plants, chiefly by way of the leaves, is called *transpiration*, but it might just as well be called plant-evaporation, for the water evaporates from the moist cells of the plant just as it does from any moist surface exposed to the air. How the leaves

are constructed so that the loss of water may not be greater than the supply will be considered later.

56. **The stem.** — An independent sporophyte has not only a vascular system and leaves, but also a stem; in fact, the presence of leaves implies a stem to bear them. The most important fact about a stem is that it bears leaves and exposes them to the air and the sunlight. In proportion as stems become taller, the better are the leaves exposed; and in propor-

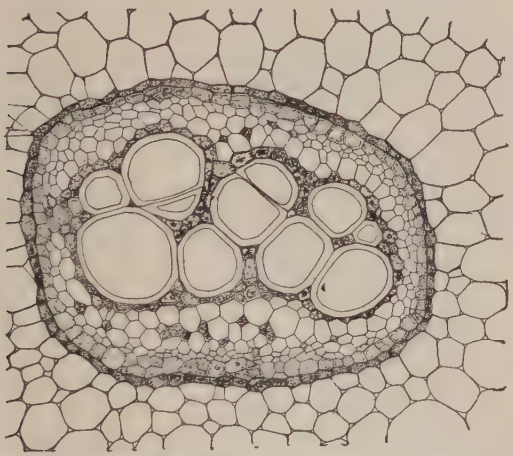


FIG. 73. — Cross-section of the central cylinder of the stem (rootstock) of a fern; the cylinder is solid, the large water-conducting vessels (xylem) being at the center.

tion as the stems become branched, more leaves can be produced and exposed.

As the stems carry the leaves up into the air and sunlight, they must also supply them with water, and this means that the vascular system of the stem must connect with the vascular system (vein system) of the leaves. In the stem the vascular system is organized as a central cylinder, so that it is called the *vascular cylinder* (Figs. 73 and 74). This cylinder not only conducts water, but also gives rigidity to the

stem, so that in most cases it stands upright. The movement of water up the stem, through the vascular cylinder, is commonly spoken of as the "ascent of sap," the "sap" being water on its way to the leaves.

It must not be supposed that all stems are upright, for in many Club-mosses they are prostrate, but as they elongate they produce and display many leaves. Nor must it be supposed that all stems are above ground, for in the most common Ferns the stem is underground, but it sends its leaves above ground. These underground stems are usually mistaken for roots, but they can always be recognized as stems by the fact that they produce leaves and by the kind of vascular cylinder they possess.

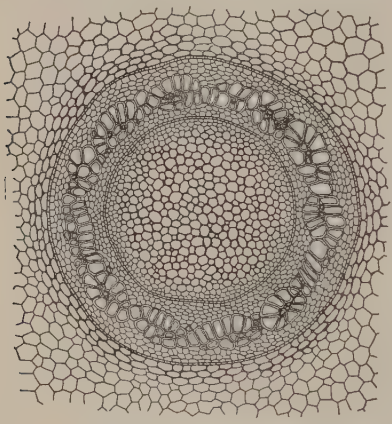


FIG. 74. — Cross-section of the central cylinder of the stem of a fern; the water-conducting vessels form a hollow cylinder inclosing pith.

57. **The root.** — An independent sporophyte has not only a vascular system, leaves, and a stem, but also roots. The leaves need water, which the stem supplies, but roots must receive water from the soil and supply it to the stem. Thus, the vascular system is a water-conducting system connecting the roots with the leaves, through the stem. No one of the four structures mentioned as belonging to an independent sporophyte is independent of the others. The presence of leaves implies a vascular system, a stem, and a root; and so for each structure in turn. They all belong together as parts of one machine. How the roots receive water from the soil will be considered later.

Roots not only receive water, but they also anchor the plant in the soil, so that the grip of the roots and the rigidity of the stem hold the plant firmly in place.

FIG. 75. — A club-moss (*Lycopodium*): *A*, the whole plant, showing the horizontal and very leafy stem giving rise to roots and erect branches bearing very distinct strobili (composed of sporophylls); *B*, a single sporophyll with its sporangium; *C*, spores much magnified. — After WOSSIDLO.

The root differs very much from the stem in structure, and especially is it different in its vascular cylinder, and in the

fact that it does not produce leaves. Like the stem, it often branches, and this means a greater capacity for receiving water. It must not be supposed that all roots are in the soil, for some roots are produced in the air by climbing stems, and anchor the stems to supports. In this case they simply act as holdfasts and do not receive water, but they can be recog-

FIG. 76. — Under surface of fern leaves, showing sori: *A*, elongated sori; *B*, round sori.

nized as roots by the vascular cylinder and by the fact that they do not bear leaves.

58. **The sporangia.** — A sporophyte, whether dependent or independent, must bear spores, and these spores must be placed in a favorable position for dispersal by air. In the dependent sporophyte of Bryophytes, the conspicuous part

of the body is a spore-case, and all the spores are produced in one continuous mass. In the independent sporophyte of Pteridophytes, however, the root, stem, and leaves are the conspicuous structures; and if the spores are to be formed in the most exposed position it is evident that they should appear in connection with the leaves. Therefore, among Pteridophytes the spore-cases (*sporangia*) are produced by

FIG. 77. — Section through a sorus of a shield fern, showing the group of sporangia covered by a shield-like (or umbrella-like) flap. — After ENGLER and PRANTL.

leaves, in some plants by all the leaves, in other plants only by certain leaves.

In the Club-mosses, with their small leaves, a single sporangium is produced on the upper surface of the leaf near its base (Fig. 75). In some of the Club-mosses every leaf has a sporangium; but in most of them only the uppermost leaves have sporangia (Fig. 75). In the latter case, there are two kinds of leaves on the plant; (1) those that bear sporangia, and (2) those that do not. The former are called *sporophylls* ("spore-leaves"), and the latter *foliage leaves* (which means ordinary green leaves).

In the Ferns, with their relatively few and large leaves, the sporangia are borne in large numbers on the under surface of the leaf, and usually occur in small groups that look like dark dots or lines (Fig. 76), which are often called "fruit-dots," but of course they are not fruit. In some Ferns almost all of the leaves bear sporangia, while in other Ferns many leaves are without them. These little groups of sporangia are called *sori* (singular *sorus*), and they are very characteristic of Ferns. A section through a sorus is shown in Fig. 77.

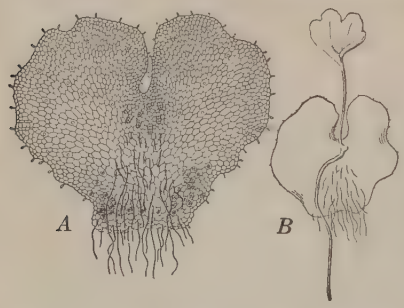


FIG. 78. — Gametophytes of ferns: *A*, a gametophyte viewed from the under side (against the substratum), showing the rhizoids and sex-organs, the archegonia (whose projecting necks are seen) being grouped near the notch, and the antheridia being grouped at the other end (in the region of the most conspicuous rhizoids); *B*, a gametophyte (under surface) from one of whose fertilized eggs (within an archegonium) a young sporophyte is developing, the root being directed downward and the leaf rising upward through the notch.

59. **The gametophyte.** — The sporophyte, with its root, stem, leaves, and sporangia, seems to most people to be the whole plant. A fern plant, as ordinarily thought of, is simply this sporophyte, and it is certainly a distinct and independent individual. But it bears no sex-organs; if it did, it would not be a sporophyte. The older observers of plants were puzzled by the absence of sex-organs in Ferns and Club-mosses, but they thought that sex-organs must be present, although invisible. Therefore, they called the group *Cryptogams*, which means "hidden sex-organs," and since Club-mosses and Ferns are vascular plants, the Pteridophytes were first called "Vascular Cryptogams," and many

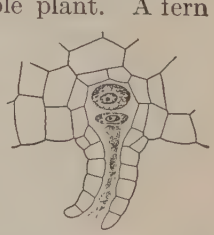


FIG. 79. — Section of an archegonium of a fern, showing the free neck, and the imbedded venter containing the egg (the large cell).

still use that name, although the sex-organs have been found.

The alternation of generations explains what was a mystery to the older botanists. When the spore of a fern germinates, it must produce a gametophyte (see § 46, p. 77). This gametophyte is a minute green plant that looks like a very small and delicate liverwort (Fig. 78, *A*). In fact, it is so small that it is only seen by those who know where to look for it; and

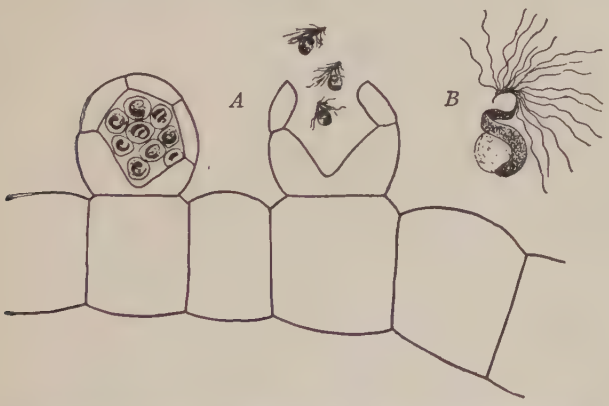


FIG. 80. — Antheridia of a fern: *A*, two antheridia, one containing sperms and the other discharging them; *B*, a single sperm, showing its coiled form and many cilia.

it does not suggest a fern in the least. Although it is flat and prostrate like a liverwort, unlike a liverwort it produces the sex-organs (antheridia and archegonia) from the under surface, against the moist substratum (Figs. 79 and 80). This position is very favorable for the swimming of sperms, for if there is moisture anywhere about the plant, it will be found between the flat body and its substratum. The necks of the archegonia also open on the under surface, so that fertilization is favored in every way.

The small gametophyte is large enough to produce sex-organs, and it does not make food for the sporophyte, so that

great exposure to drying out is avoided, and fertilization is assured.

When the fertilized egg in the archegonium germinates, it produces the large, independent sporophyte which is recognized as "the fern" (Fig. 78, *B*).

FIG. 81. — *Equisetum:* showing the jointed and fluted stem, the sheath of minute leaves at each joint, strobili in various stages of development, and some young branches.

It may have been difficult for some to think of the sporecase of a liverwort or a moss as being an individual distinct from the green plant that bears it; but when in the Ferns these two individuals become entirely independent of one another, the difficulty disappears.

60. **The great groups of Pteridophytes.** — The Pteridophytes are very ancient plants, for their history has been traced back to the time when coal was formed, and even before that time. Their remains are found in the rocks, and this record of their existence has shown not only that they were very abundant, but also that they were different from the Pteridophytes that are living to-day. A number of great groups lived and flourished and then disappeared, but they

produced descendants, and among these descendants are the Pteridophytes of the present time. The history and fate of these ancient groups may be likened to the history and fate of such old empires as those of Egypt, Greece, and Rome, which lived and flourished and then disappeared, but they also gave rise to descendants, and among these descendants are various nations of the present time.

Fig. 82. — A branching *Equisetum*.

There are three prominent groups of Pteridophytes living to-day, and they are common enough to deserve recognition.

(1) *Club-mosses* (*Lycopodiales*).—These plants, resembling coarse mosses, are recognized by their numerous small leaves (Figs. 71 and 75), and by the fact that the sporangium-bearing leaves (sporophylls) bear a single sporangium upon the upper surface near the base. They are sometimes called "ground pines," because the coarser ones resemble seedling pines in general appearance. Among the ancestors of the present Lycopodiales there were large trees, so that during the Coal Age the

Lycopodiales were conspicuous members of the forests. At present, however, they are all small and mostly prostrate plants that send up vertical branches bearing the sporangia.

(2) *Horsetails* (*Equisetales*). — These plants are sometimes called "scouring rushes," and are so peculiar in appearance that they can never be mistaken. The stems are green and jointed, and often the joints can be pulled apart easily (Fig. 81). At each joint there is a circle of minute leaves forming

FIG. 83. — Young fern leaves arising from the subterranean stem (rootstock), and showing the rolled tip.

a toothed sheath, but they are not foliage leaves, for they do not display green tissue. As a consequence, the stem looks bare, which is especially noticeable when it does not branch. When branching occurs, it may be very profuse, so that the plant looks like a miniature bush (Fig. 82). Since there are no foliage leaves, all the work of food manufacture must be done by the green tissue of the stem.

The Equisetums (which seems to be a better name to use

FIG. 84. — Mexican tree ferns (*Alsophila*). — Photograph by LAND.

than horsetails) also have forest trees among their ancestors of the Coal Age, and the appearance of these conspicuously jointed trees would have been very peculiar to one familiar only with trees of the present day. Many of the ancient representatives of the group had foliage leaves, and in some cases large ones, so that the living Equisetums are rather poor representatives of the group.

(3) *Ferns* (*Filicales*). — These are the most abundant and best known of the Pteridophytes, and hardly need a definition. Compared with Club-mosses, Ferns have large and relatively few leaves, which bear numerous sporangia upon the under surface. Not only are the leaves large, but sometimes they become very large by branching. It is not by its form that a fern leaf can be distinguished from other leaves, but by its forking veins (Fig. 70), and by the fact that it first appears as if rolled up from the tip to the base, and then it expands by unrolling (Fig. 83). The leaves of Ferns were once called "fronds," because they were thought to be different from leaves. It was observed that they came directly from the ground, arising from an underground structure that was thought to be a root (Fig. 83). Therefore, the leaf-like structure was thought to be a combination of stem and leaf, to which the name "frond" was given. Of course a fern leaf is not a frond, as the underground structure referred to is a stem and not a root, but many still call it a frond.

The Ferns of ordinary experience are tufts of leaves arising from an underground stem (Fig. 72), which also sends out roots; but there are many tree Ferns in the tropics, the unbranching trunk (often tall and slender) bearing a crown of large and branching leaves (Fig. 84); and there are climbing Ferns in our own eastern mountain region; and numerous perching Ferns occur in the tropics, often covering the trunks and branches of trees (Figs. 85 and 86).

61. **The strobilus.** — This word means "cone," and its use here refers to the fact that in some Pteridophytes the

Fig. 85. — Perching ferns (with hanging leaves) on a tree in Mexico. — Photograph by Land.

FIG. 86. — A large staghorn fern perching on a tree in Australia. — Photograph by CHAMBERLAIN.

sporophylls (see § 58, p. 97) become different in appearance from the foliage leaves (usually smaller, and often different in form), and are grouped close together in the form of a cylinder or cone (as in the pine cone). This group or cone of

sporophylls is the *strobilus* (Figs. 75 and 81), and it is a very important structure, for it is the precursor of the flower.

In general, the Club-mosses have strobili very distinct from the rest of the body (Fig. 75), for they are borne at the ends of the vertical branches, and are often stalked far above the foliage-bearing part of the stems. It is these strobili that are the "clubs" of the Club-mosses, a name which may now be interpreted as meaning moss-like plants that bear clubs. It must be kept in mind that in these strobili of Club-mosses, each sporophyll bears a single large sporangium on its upper surface near the base, and that a strobilus is simply the tip of a stem (or branch) bearing sporophylls so close together that they overlap.

The Equisetums also have strobili (Fig. 81), and the sporophylls are very different from those of the Club-mosses, for each sporophyll is a stalk-like structure with an expanded top (" peltate "), from the under side of which several sporangia are suspended (Fig. 87).

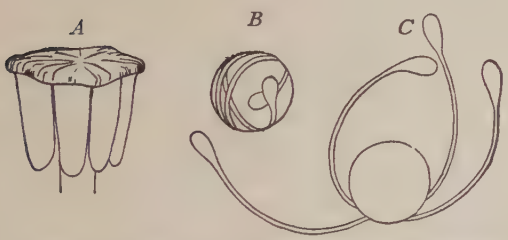


FIG. 87. — *Equisetum: A*, a single sporophyll, showing the peltate top from which the sporangia hang; *B* and *C*, spores showing the unwinding of the peculiar bands that form the outer coat.

FIG. 88. — *Ophioglossum* (adder's tongue): a fern with a part of the leaf bearing sporangia.

The Ferns do not have strobili, although in some of them there are sporophylls distinct from foliage leaves, and in more

of them certain branches of the leaf bear sporangia and differ very much in appearance from the foliage branches (Fig. 88). But in no case are sporophylls grouped together to form strobili.

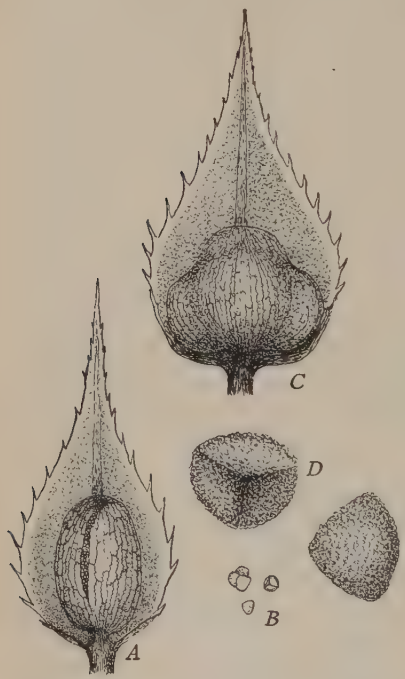


FIG. 89. — *Selaginella* (a club-moss): *A*, a sporophyll (microsporophyll) bearing the sporangium (microsporangium) that produces small spores (microspores); *B*, microspores (lowest one separate, upper ones clinging together); *C*, a sporophyll (megasporophyll) bearing the sporangium (megasporangium) that produces large spores (megaspores); *D*, two megaspores, drawn to the same scale as the microspores (*B*).

62. **Heterospory.** — In most of the Pteridophytes, all the spores produced by the sporangia are alike, both in appearance and in the gametophytes they produce. This condition is called *homospory* ("similar spores"), and such plants are *homosporous*.

In some Pteridophytes, however, notably one kind of club-moss (*Selaginella*, Fig. 71), the spores are not all alike (Fig. 89). They differ very much in size, the large ones being called *megaspores* ("large spores") and the small ones *microspores* ("small spores"). Not only do they differ in size, but they differ also in the gametophytes they produce, the megaspores producing female gametophytes (that is, gametophytes that bear only archegonia), and the microspores producing male gametophytes (that is, gametophytes that bear only antheridia). This condition is called

heterospory ("different spores"), and such plants are *heterosporous.*

Heterospory is extremely important, for it is the condition that leads to seed-formation; that is, heterospory is the precursor of the seed. Pteridophytes in general are not heterosporous, but heterospory began among Pteridophytes, and when it reached the formation of seeds, then Seed-plants (Spermatophytes) began.

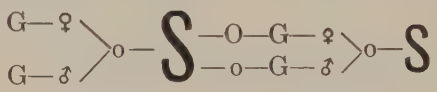
Not only are the spores of heterosporous plants different, but the two kinds are produced by different sporangia (Fig. 89). Therefore the sporangia that produce megaspores are called *megasporangia,* and those that produce microspores are called *microsporangia.* In *Selaginella* (the heterosporous Club-mosses) the megasporangia are usually in the lower part of the strobilus, and the microsporangia in the upper part. The difference in the size of the spores involves a difference in the number of spores produced by the two kinds of sporangia. In *Selaginella,* for example, a megasporangium usually contains four megaspores, while a microsporangium contains hundreds of microspores. Since the two kinds of sporangia are approximately of the same size, this difference in the number of spores will give some idea of their difference in size (Fig. 89).

It is necessary also to recognize the fact that the sporophylls that produce the two kinds of sporangia may become different; in fact, among the Seed-plants they become very different. In order to distinguish them, the sporophylls producing megasporangia are called *megasporophylls;* while those producing microsporangia are called *microsporophylls.*

A little experience with these terms will make them recall easily the structures they stand for, especially if their relations are remembered as follows: a megasporophyll bears one or more megasporangia, which contain megaspores; and when megaspores germinate, they produce female gametophytes, that is, gametophytes that bear only archegonia

(which contain the eggs); a microsporophyll bears one or more microsporangia, which contain microspores; and when microspores germinate, they produce male gametophytes, that is, gametophytes that bear only antheridia (which contain the sperms).

It may help to remember what heterospory involves in the life-history of a plant by giving the formula of the life-history of a heterosporous plant, which of course must include two gametophytes. The sexual cells (egg and sperm) are indicated by the conventional sex signs (♀ is for female, and ♂ for male), and the two kinds of spores are indicated by their relative size.



Among the Seed-plants it often happens that the megaspores and microspores are borne on different sporophytes, so that in such life-histories two sporophytes must be included, as well as two gametophytes. Two sporophytes would need two eggs, so that the formula becomes somewhat complicated, but it gives some appreciation of the machinery of the higher plants.

63. **Gametophytes.** — In § 59 (p. 98) the gametophyte of a fern was described, which may stand in a general way for the gametophytes of most Pteridophytes, for most Pteridophytes are homosporous. These gametophytes are alike in usually bearing both sex-organs, therefore they are not male or female, but both; and also they are quite independent of the sporophyte which produced them by means of its spores.

But in heterosporous plants there are two kinds of gametophytes, and these must be described if one is to understand seeds when they appear.

When a microspore germinates, there appears within it a small group of cells, but the group never grows so as tc

break through the wall of the microspore and develop a free plant (Fig. 90). When it is remembered that whatever a microspore produces must be a male gametophyte, no matter what it looks like, this small group of cells within the microspore must be the male gametophyte. When the group is examined, it is discovered that there is a single antheridium, with its wall inclosing sperm-producing cells. This represents a gametophyte that has disappeared from ordinary sight, and that can be discovered only by the microscope.

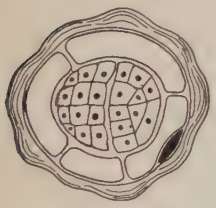


FIG. 90. — *Selaginella:* the male gametophyte completely developed within the microspore; the group of squarish cells with nuclei are those that produce sperms. — After Miss LYON.

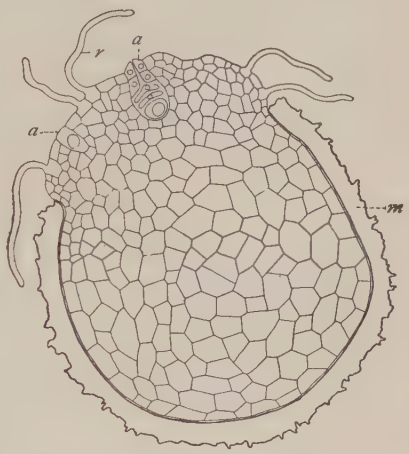


FIG. 91. — *Selaginella:* the female gametophyte within the megaspore, but having burst through on one side: *m*, megaspore wall; *a*, archegonium; *r*, rhizoid.

When a megaspore germinates, there appears within it a much larger group of cells than appears in the microspore (Fig. 91), for the megaspore is much larger than the microspore. But even this larger group of cells does not free itself from the megaspore wall and grow into a free plant; but it does develop archegonia, and must be the female gametophyte.

In heterosporous plants, therefore, the two gametophytes

have disappeared from ordinary sight, and it is not surprising that the large and conspicuous sporophyte is thought to be the whole of the plant; it is certainly the whole of the plant in sight. To find the gametophytes, one must look within the microspores and megaspores with a microscope.

It is instructive to trace the history of the gametophyte and sporophyte generations through the great groups of plants. In Bryophytes, the gametophyte is the conspicuous individual, the sporophyte being dependent upon it and being not much more than a spore-case. In the Pteridophytes, the sporophyte has become the conspicuous individual, but in most Pteridophytes the gametophyte is a free and independent individual, although relatively very small. In the heterosporous Pteridophytes and in all the Seed-plants, the gametophytes are neither free nor independent, and have disappeared from view within the spores that produce them. The accompanying diagram (Fig. 92) will illustrate the gradual advance of the sporophyte and the gradual decline of the gametophyte through the plant kingdom.

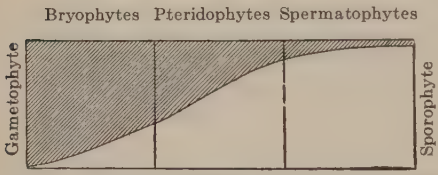


FIG. 92. — Diagram illustrating the advance of the sporophyte and the decline of the gametophyte through Bryophytes, Pteridophytes, and Spermatophytes.

64. **Summary.** — The most important fact in connection with the Pteridophytes is the appearance of an independent sporophyte, which is now the conspicuous generation. With the appearance of an independent sporophyte there are associated three structures not found in the lower groups of plants: the vascular system, the sporophyte leaves, and the root.

A second important fact is that among the Pteridophytes the strobilus appears, which is the precursor of the flower.

The strobilus is not a feature of all Pteridophytes, not appearing among the Ferns, but it is a structure begun by the group.

A third important fact is the appearance of heterospory, for this is the precursor of the seed. This means a differentiation of the spores into two kinds, one kind (the smaller ones) producing the male gametophytes, the other kind (the larger ones) producing the female gametophytes. Another accompaniment of heterospory is that the gametophytes are dependent and so small that they remain within the spores that produce them.

CHAPTER VII

SPERMATOPHYTES. — 1. Gymnosperms

The First Seed-plants

65. **The great plant groups.** — In beginning a study of the fourth great group of plants, it is appropriate to fix in mind the chief distinguishing features of all the groups. The following statement of contrasts may serve this purpose.

Thallophytes. — Plants with a thallus body, but no archegonia.

Bryophytes. — Plants with archegonia, but no vascular system.

Pteridophytes. — Plants with a vascular system, but no seeds.

Spermatophytes. — Plants with seeds.

Each of the definitions (except the last) contains a positive and a negative statement, the positive statement distinguishing the group from the one below it in rank (except the first), and the negative statement distinguishing the group from the one above it in rank.

The four great groups should not only be kept clearly in mind by brief definitions, such as those given above, but they should also be remembered for their chief contributions to the progress of the plant kingdom. The most conspicuous contributions may be stated as follows.

Thallophytes. — This group, as represented by the Algæ, stands for the beginnings of plant structures, and chiefly for the evolution of the three kinds of reproduction.

Bryophytes. — This group, as represented by the Liverworts, stands for acquiring the land habit (which means air

as a medium), and for establishing the alternation of generations.

Pteridophytes. — This group stands for the development of the vascular system (with its associated leaves and roots), for the introduction of the strobilus, and for the beginning of heterospory.

Spermatophytes. — This group stands for the development of the seed and for the evolution of the flower.

66. **The two great groups of Seed-plants.** — The Seed-plants are the most conspicuous plants to-day, for they make up nearly all the vegetation that one sees. They are certainly more important than the other groups, not only in prominence and in numbers, but also in the use made of them. They are so prominent and useful that they were once thought to be the only group worth studying; but it is known now that Seed-plants can be understood best by allowing the other groups to explain them.

The Seed-plants have developed as two great groups: (1) those in which the seeds are exposed, and (2) those in which the seeds are inclosed. The first group is named *Gymnosperms* ("naked seeds"), and the second is named *Angiosperms* ("inclosed seeds"). The Gymnosperms are the ancient Seed-plants, and are now much less numerous than the more modern Angiosperms. It is the Gymnosperms, therefore, that developed the first seeds and that must be considered first.

67. **The ancient Gymnosperms.** — In most ancient times in which we have plant records, when the coal was being formed, and there were tree Club-mosses and tree Equisetums, the oldest Gymnosperms lived. They were very abundant, for their leaves are found everywhere in the rocks about the coal mines. The leaves resemble those of Ferns so exactly that they were thought to belong to Ferns, but recently it was discovered that they bore seeds, and therefore they are Gymnosperms. The first Seed-plants, therefore,

looked like Ferns bearing seeds, and it is believed that they came from very ancient Ferns by acquiring the seed habit.

These fern-like Gymnosperms gave rise to other groups, and these in turn to still others, until finally the Gymnosperms of to-day appeared.

68. **The modern Gymnosperms.** — The greatest group of modern Gymnosperms is the one to which pines, spruces,

FIG. 93. — A group of Conifers (mostly spruces) along the southern boundary of the White River Forest Reserve, Colorado.—Photograph by LAND.

hemlocks, cedars, etc., belong (Fig. 93), and is called Conifers ("cone-bearers") on account of the cones the plants (usually trees) bear. These Conifers are found in forest masses, sometimes very extensive, throughout the north temperate regions, and they extend farther south along the mountain ranges. Many of them are extremely valuable for timber, and it is well known how extensively and ruthlessly they have been destroyed by man. In the temperate regions of the southern hemisphere there is also a great display of Conifers that differ from those of the northern hemisphere.

Scattered through the broad tropical belt between the two temperate regions there is another group of modern

Fig. 94. — A Mexican Cycad (*Dioon edule*). — Photograph by Chamberlain.

Gymnosperms, called Cycads. They resemble tree ferns, with their columnar trunks bearing crowns of large fern-like

leaves (Fig. 94). Sometimes the trunks are short, resembling casks or large tubers, but they always bear the crown of fern-like leaves.

There are two other living groups, very much scattered, and very few in numbers, so that they need not be described.

The pine will be used as a representative of Gymnosperms, since it is a conspicuous and familiar form.

69. **The sporophyte.** — The pine "tree" is of course a sporophyte that has become very large (Fig. 93). The vascular cylinder of the stem is thick, and it becomes thicker each year by adding new layers of wood. This continual increase in the amount of water-conducting tissue makes wide and continued branching possible, for branching means an increase in leaf display, and increased leaf display means a larger supply of water not only for food manufacture, but chiefly to supply the loss from the leaves. The tree type of body, with its tall trunk and spreading branches bearing a great mass of foliage, is the most advanced type of sporophyte body. In other words, it is the sporophyte at its best.

In the pine the leaves are not broad, being only green "needles," but they are very numerous (Fig. 95). There are Conifers, however, with broad leaves, and the Cycads have very large fern-like leaves (Fig. 94).

70. **The strobili.** — A pine tree bears two kinds of strobili ("cones"), but many Gymnosperms have the two kinds of strobili on different trees. The pine cone that is ordinarily seen is the strobilus that bears megasporangia; that is, it is a group of megasporophylls. It is so much larger and more persistent than the other kind that to most people it seems to be the only kind of cone on the tree. But there are also small strobili composed of groups of microsporophylls bearing microsporangia (Fig. 95).

Ovulate strobilus. — If one of the larger cones of the pine is cut through lengthwise (Fig. 96, *A*), it will be found to

consist of a central axis bearing numerous close-set megasporophylls, which are very firm, and finally become very hard. On the upper side of each megasporophyll near the

FIG. 95. — Tip of a pine branch, showing ovulate cones of first year (*a*), second year (*b*), and third year (*c*); also a cluster of staminate cones (*d*).

base are two megasporangia, lying side by side (Fig. 96, *B* and *C*). The megasporophylls lie so close together that the megasporangia cannot be seen from the outside, but when the

strobilus matures, the hard megasporophylls spread apart and the megasporangia become exposed.

These structures of Seed-plants were known long before the corresponding structures of the lower groups, and of course they received names. It is necessary now to fit the two sets of names together, so as to recognize what the old names really stand for. The megasporophylls of Seed-plants were called *carpels*, long before they were known to represent structures belonging to Pteridophytes. Approaching them from the Pteridophytes, we find that the so-called carpel of Seed-plants is a megasporophyll, and this is an illustration of what was meant when it was stated that a lower group of plants explains a higher one.

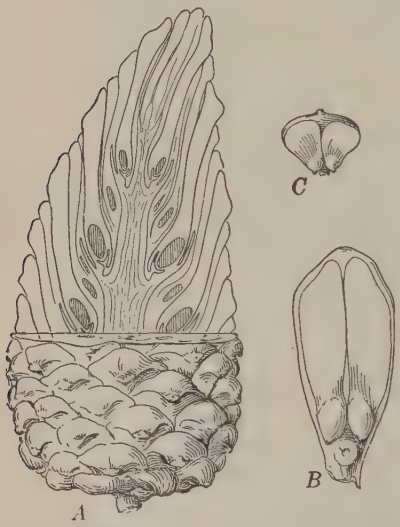


FIG. 96. — Ovulate cone of pine: *A*, cone partly sectioned, showing the central axis and the overlapping carpels ("scales") bearing ovules (megasporangia) near the base; *B* and *C*, single carpels, showing the pair of ovules borne on the upper side.

The megasporangia of Seed-plants were called *ovules* (the structures that become *seeds*), and thus we learn that the ovules of Seed-plants are megasporangia. This is important, because ovule means "a little egg," and the thought was that the ovule is an egg. The previous chapters have made it plain that an egg and a sporangium are about as different as two structures can be; not only that, but that the egg belongs to the gametophyte, and the sporangium to the sporophyte. The word "ovule" is not likely to be dis-

carded, although its real meaning records a mistake, for it has been long used and is shorter than megasporangium. In using it, however, it must be realized that "ovule" is just another name for the megasporangium of Seed-plants.

It is convenient to have a name to distinguish the strobilus that bears ovules (megasporangia) from the one that does not, and the most appropriate one seems to be *ovulate strobilus* or *ovulate cone*. Some persist in calling the ovulate cone the "female cone"; but the cone (strobilus) is made up of sporophylls borne by a sporophyte, so that it cannot very well be either male or female, terms that belong to the gametophyte.

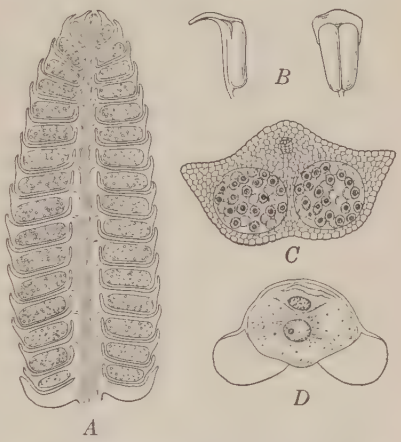


FIG. 97. — Staminate cone of pine: *A*, longitudinal section of cone, showing the stamens (microsporophylls) bearing pollen sacs (microsporangia) upon the under side; *B*, views of stamen from the side and from below, the latter showing the two pollen sacs; *C*, cross-section of a stamen, showing the two pollen sacs containing pollen grains (microspores); *D*, a winged pollen grain, showing within the early cells of the male gametophyte.

Staminate strobilus. — The smaller cone of the pine will be found to consist of microsporophylls borne upon a central axis, much smaller and more delicate than the megasporophylls (Fig. 97, *A*). On the under side of each microsporophyll are two microsporangia, lying side by side (Fig. 97, *B* and *C*). The old names for these structures among Seed-plants are as follows: the microsporophylls were called *stamens*, the microsporangia were called *pollen sacs*, and the microspores were called *pollen grains* or simply *pollen*. In this way it has become evident that such well-known struct-

ures among Seed-plants as stamens, pollen sacs, and pollen grains, correspond to the microsporophylls, microsporangia, and microspores of the Pteridophytes.

Since stamen is so much more convenient a term than microsporophyll, the cone which bears microsporangia (pollen sacs) may be called the *staminate strobilus* or *staminate cone*, but it should be realized that "stamen" is only another name for the microsporophyll of Seed-plants. It is the staminate cone that is often called a "male cone," which is no more appropriate than to call the ovulate cone a "female cone." Also, there is no objection to calling the microspores "pollen," provided it is remembered that "pollen" is only another name for the microspores of Seed-plants.

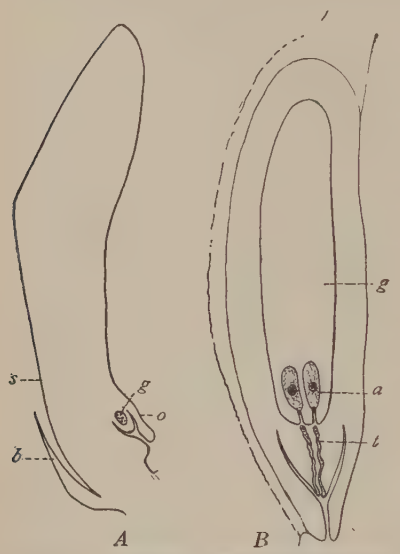


FIG. 98. — *A*, section of scale of ovulate cone, showing the bract beneath (*b*), the scale (*s*), the ovule (*o*), with its integument and nucellus, and within the nucellus the megaspore (*g*) which probably contains the beginning of the female gametophyte; *B*, a section through the ovule a year later, showing the large female gametophyte (*g*) with two archegonia (*a*) which are being reached by pollen tubes (*t*) penetrating the tip of the nucellus; observe also the integument at the top of the ovule with its passage way (micropyle) to the nucellus.

71. **The ovule.** — It is the ovule (megasporangium) that distinguishes Seed-plants, for it develops into the seed, and therefore it must differ somewhat from the megasporangia of Pteridophytes. If it is cut through lengthwise, its general structure will be evident (Fig. 98, *A*). On the outside of it there is a covering which is loose above and extends into a

more or less extended tube. The covering is the *integument*, and the tube is the *micropyle* ("little gate"). Within the covering is the body of the ovule (*nucellus*), with its tip at the base of the open micropyle. If the ovule is a megasporangium, it must contain megaspores, and these are found in the nucellus. Several megaspores start, but only one grows, and it becomes so large that it looks like a cavity in the middle of the nucellus (Fig. 98, *A*). The peculiarity of this megasporangium (the ovule) is not that it has only one megaspore, or that the megaspore is so large, but that it is never shed, that is, it never escapes from its megasporangium. The fact that this megaspore is retained in its sporangium is the reason why the ovule becomes a seed.

72. **The stamen.** — There is nothing peculiar about the stamen (microsporophyll), except that among Gymnosperms it becomes more and more unlike a leaf in appearance. In some Cycads it appears as a flat blade bearing sporangia (pollen sacs) on its under surface; in pines the blade becomes short-stalked (Fig. 97, *B*); and in many other Gymnosperms the stalk becomes elongated and the blade reduced to a plate or knob bearing the pollen sacs. When two regions of a stamen are distinguishable as a stalk region and a pollen-sac region, the former is called the *filament*, and the latter the *anther*. These names are often convenient in describing stamens, but they only mean that some microsporophylls have stalks distinct from the sporangium-bearing region.

73. **The gametophytes.** — In the preceding chapter (§ 63, p. 110) it was stated that the gametophytes of heterosporous Pteridophytes do not emerge from the spores that produce them. Of course all Seed-plants are heterosporous, and, therefore, just as in heterosporous Pteridophytes, the male gametophyte develops within the microspore (pollen grain), and the female gametophyte develops within the megaspore which is retained within the megasporangium (ovule). This means that in Seed-plants the gametophytes are in-

visible to the ordinary observer, for they are living, like internal parasites, within structures of the sporophyte.

The female gametophyte. — The large, solitary megaspore within the ovule develops within itself the female gametophyte, which consists of numerous cells (Fig. 98, *B*). Cells on the side of the gametophyte towards the tip of the nucellus, which means also towards the micropyle, develop archegonia (Fig. 98, *B*), and in each archegonium, of course, there is an egg. It becomes evident now that an " ovule " is very far from being an egg, although it received its name because it was thought to be an egg. It is helpful in fixing the relations of parts to remember that the egg is in an archegonium, the archegonium is produced by the gametophyte, the gametophyte is within the megaspore, and the megaspore is within the ovule (megasporangium). Of course the egg is passive and remains in the archegonium, awaiting fertilization.

The male gametophyte. — The microspores (pollen grains) do not remain within the microsporangia (pollen sacs), but are discharged and are widely scattered by the wind. When the pollen of pines is being shed, the air is sometimes full of the small " grains " (spores), which look like yellow powder, and they settle down like rain. In the pines, the pollen grains have wings (Fig. 97, *D*), but this is not true of all Conifers. Of course very few pollen grains land on the right spots, but there are so many of them that some reach the proper landing places. The " right spots " are the ovulate cones, whose hard megasporophylls (carpels), often called the " scales " of the cone, have spread apart to receive them. The minute pollen grains slip down the sloping scale and collect in a little drift at the bottom, around the projecting micropyle. Then some of them get into the micropyle and reach the tip of the nucellus, which is their destination. This transfer of pollen from the pollen sacs (microsporangia) to the ovulate cone, and in the cone to the tip of the nucellus,

is called *pollination*, and in the Gymnosperms the agent of this transfer is the wind. Such plants, therefore, are said to be *wind-pollinated*.

Before the pollen grains (microspores) leave the pollen sacs, the male gametophyte has begun to develop within them (Fig. 97, *D*), and after the pollen has reached the nucellus, the gametophyte continues to develop, forming an antheridium, which in almost every Gymnosperm produces two sperms. In the Cycads these sperms have cilia and swim (Fig. 99), just as do those of the Pteridophytes; but in the Conifers the sperms have no cilia, and of course do not swim.

Fig. 99. — Two views of the sperm of a Cycad, showing its spiral form and many cilia.

74. **Fertilization.** — After pollination has been accomplished, and the pollen grain (microspore) of the pine, with its contained male gametophyte, is resting on the tip of the nucellus, the sperms and the eggs are separated from one another by the mass of tissue that forms the top of the nucellus. This tissue must be penetrated, and the pollen grain (really the male gametophyte within it) puts out a tube (*pollen tube*) which grows into it, crowding its way among the cells, absorbing nourishment from them like an internal parasite, and finally reaches the egg (Fig. 98, *B*). In the tip of the advancing tube the two sperms are lying, and when the vicinity of the egg is reached, they are discharged from the tube, and one of them penetrates the egg and the two nuclei fuse. The result, of course, is a fertilized egg lying deep in the ovule.

Pollination and fertilization should not be confused, as they often are. When pollen is carried to an ovulate cone

of a pine (or to a flower in higher plants) it is often called "fertilization," but it is evident that it is not. Pollination is a performance that must precede fertilization, and it may or may not be followed by fertilization, which is the fusion of a sperm and an egg.

75. **The embryo.** — The fertilized egg, lying within the ovule, begins to germinate almost at once, and as the young sporophyte (*embryo*) grows, it feeds upon the surrounding cells of the female gametophyte, and finally reaches a stage in which the different parts become distinguishable (Fig. 100, *A*). In the pine, the three regions are a stem-like part (*hypocotyl*) whose tip is directed towards the top of the nucellus (which means that it is directed towards the micropyle); a rosette of leaf-like parts (*cotyledons*); and in the midst of the rosette of cotyledons, and resting on the top of the hypocotyl, a minute bud-like part (*plumule*). The hypocotyl will later develop the root, the plumule will develop the stem and leaves, and the cotyledons will for a short time supply nourishment to the young plant.

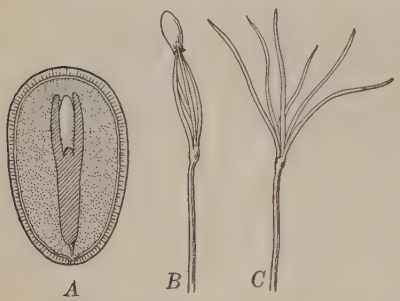


FIG. 100. — *A*, section of a pine seed, showing the hard coat (testa), the female gametophyte (dotted) which has grown to the testa and is usually called endosperm, and the embryo (also sectioned) with its hypocotyl, its cotyledons (three only are shown), and the plumule (the short protuberance) surrounded by the cotyledons; *B* and *C*, germination of the pine seed, the cotyledons backing out of the testa in *B* and entirely free in *C*.

Although the fertilized egg germinates almost at once, and the embryo grows until the three regions described appear, it does not continue to grow without interruption, but passes into what is called the dormant ("sleeping") stage, and the dormant embryo is one of the peculiarities of Seed-plants.

Just what conditions result in dormancy we do not know in all cases, but we do know some facts that are associated with it. What these are will be described in the next section.

76. **The seed.** — While the embryo is being formed, changes are taking place in the integument of the ovule. A new kind of tissue begins to develop from the cells of the integument, and continues to develop until it forms a hard covering that completely invests the ovule, the only breaks in it being at the micropyle (whose position is indicated by what looks like a small scar) and at the point where the ovule (megasporangium) was attached to the carpel (megasporophyll). When this hard coat (*testa*) is complete, the ovule has become a seed (Fig. 100, *A*).

It is evident that the seed is a very complex structure, and that it has resulted from the retention of the megaspore within the megasporangium (ovule), so that within this sporangium the female gametophyte develops, fertilization takes place, and the young sporophyte (embryo) is formed. In a seed, therefore, three generations are represented: (1) the old sporophyte, represented by the ovule structures; (2) the female gametophyte, very commonly called the *endosperm* of seeds; and (3) the young sporophyte (embryo). It is a simple thing to observe the structure of a seed and to watch its "germination," but really to know the structure of a seed needs the approach to it from the lower groups of plants.

A seed is said to "germinate," but it is plain that it is not germination in the sense we have been using that word, for only spores and fertilized eggs (oöspores) germinate. Besides, germination occurs when the fertilized egg within the ovule produces the embryo; therefore, when a seed is said to "germinate," the real germination had occurred long before, usually the preceding season, sometimes many seasons before. What "seed germination" means, therefore, is not real germination, but the "awakening" of the young

sporophyte (embryo) from its dormant condition, and the resumption of its growth, and its escape from the seed coat (Fig. 100, *B* and *C*). Of course seeds will always be said to "germinate," for the word is too firmly established in this connection to be changed, but the student of botany should realize that "seed-germination" is not the starting of a new individual (which is real germination), but the continued growth of an individual that has been started already. The resumed growth of the embryo, and its escape as a "seedling," will be considered in connection with the other great group of Seed-plants, whose seeds are those most frequently "germinated" by those who cultivate plants.

77. **Summary.** — The Gymnosperms are the most ancient Seed-plants, continuing and advancing the structures of the Ferns, from which they differ chiefly in the presence of seeds. The vascular system is notably developed, resulting in larger sporophyte bodies, and in a greater display of foliage. The earliest Gymnosperms did not have strobili, resembling the Ferns in this feature, but all other Gymnosperms have strobili as a very conspicuous feature.

The important fact about Gymnosperms, however, is the existence of seeds. A seed is derived from an ovule, and an ovule is a megasporangium. The difference between an ovule and any other megasporangium is that the ovule retains its megaspores instead of shedding them. This retention of the megaspore means that the female gametophyte develops within the ovule, that fertilization occurs there, and that the embryo sporophyte develops there. When all of these structures within the ovule become incased by a hard coat (testa), the total structure is the seed.

The transportation of pollen (pollination) is effected by the wind, and after fertilization the embryo develops three regions (hypocotyl, cotyledons, and plumule) and then passes into a dormant stage. Activity is resumed when the conditions for "seed-germination" are present.

CHAPTER VIII

SPERMATOPHYTES. — 2. Angiosperms

The Real Flowering Plants

78. **General character.** — The Angiosperms have several superlative features. They are the most advanced, the most recent, the most conspicuous, and the most useful of plants. The vegetation that covers the earth is in the main angiosperm vegetation, and when to this is added the fact that the Angiosperms are almost the only plants that men use, it is not strange that they were once thought to be the only plants worth studying. Perhaps the best reason for studying the lower groups is that Angiosperms may be understood better. Some more definite appreciation of the relative abundance of Angiosperms may be obtained from the statement that about 450 different kinds (species) of living Gymnosperms are known, while about 130,000 different kinds of Angiosperms have been recorded.

In the preceding chapter (§ 66) it was stated that Angiosperms differ from Gymnosperms in having the seeds inclosed. The inclosing structure is the carpel, which thus forms a "seed-vessel" of extremely variable appearance. Using the terms applied to these structures in the lower groups, the statement would be that the megasporophyll incloses the megasporangia (ovules). It must not be thought that the inclosure of the ovules is the only character that distinguishes Angiosperms from Gymnosperms. It is so obvious a feature that it suggested the name of the group, but there are many other important differences.

79. **The sporophyte.** — The habit of the sporophyte, as its general appearance is called, shows every possible variation, as would be expected in so large a group. One of the oldest groupings of plants recognized this fact in classifying them as herbs, shrubs, and trees. Of course these names are retained for general use, but they cannot be defined with exactness.

The sporophyte is extremely variable not only in habit, but also in structure. In general, the structure of the stems and leaves is quite different from that found among Gymnosperms, almost every trace of the ancient fern connection having disappeared. The root, stem, and leaf are such important organs that they deserve separate treatment, and this has been deferred until the greatest display of these organs has been reached in the Angiosperms. Their place in the history of the plant kingdom has been stated, but it remains to consider their work, especially as such knowledge is essential to any intelligent cultivation of plants. This subject will be treated in subsequent chapters.

80. **The flower.** — The most characteristic structure of Angiosperms is the *flower*. This does not mean that all Angiosperms have flowers, but that Angiosperms have developed the flower. In § 61 (p. 107) it was stated that the strobilus is the precursor of the flower. Throughout Gymnosperms the strobilus is the nearest approach to the flower, and among the simpler Angiosperms the strobilus continues.

It is necessary to have clearly in mind the distinction between a strobilus and a flower. It is a distinction of convenience and not of exactness, for the two structures grade insensibly into one another. A strobilus is a group of sporophylls, organized together so as to form a structure distinct from the foliage-bearing part of the plant. A strobilus-bearing plant, therefore, has two kinds of lateral members: sporophylls and leaves. A flower introduces a third lateral member, the *perianth*, which is associated with the sporo-

phylls. A flower, therefore, may be said to be a strobilus with a perianth. Originally a flower was thought to be essentially a group of sex-organs, and therefore a sexual structure. It is evident that it consists of members (perianth and sporophylls) borne by a sporophyte, and therefore it cannot be a sexual structure. It is impossible to apply the term strobilus and flower strictly among Angiosperms, for some flowers have no perianth because they have never had one, and therefore are strobili; and others have no perianth because they have lost it, and therefore are flowers by descent. Among Angiosperms, therefore, it is convenient to speak of all sporophyll-bearing structures as flowers.

FIG. 101. — Flower of peony: *k*, sepals (forming the calyx); *c*, petals (forming the corolla); calyx and corolla together constitute the perianth; *a*, stamens; *g*, carpels (or pistils). — After STRASBURGER.

81. **The perianth.** — It is evident that the perianth is the distinguishing mark of a flower; in fact, it is just the mark that people in general use in recognizing a flower. One of the features of Angiosperms is the endless variation in the structure of the perianth, so that the different kinds of flowers become the most valuable means of classifying Angiosperms.

The term perianth is a collective one, to include all the members; but it is used chiefly in cases where the members are all approximately alike, as in the lilies and their allies. In most Angiosperms, however, the perianth is differentiated into two sets, *calyx* and *corolla* (Fig. 101). The calyx, whose individual members are called *sepals*, is the outer set and usually green in color; while the corolla, whose

individual members are called *petals*, is variously and usually brightly colored, forming the showy part of the flower. In fact, it is the corolla that usually gives character and attraction to the flower. These general statements in reference to the calyx and corolla must not be applied too rigidly. For example, the calyx may be brightly colored and showy,

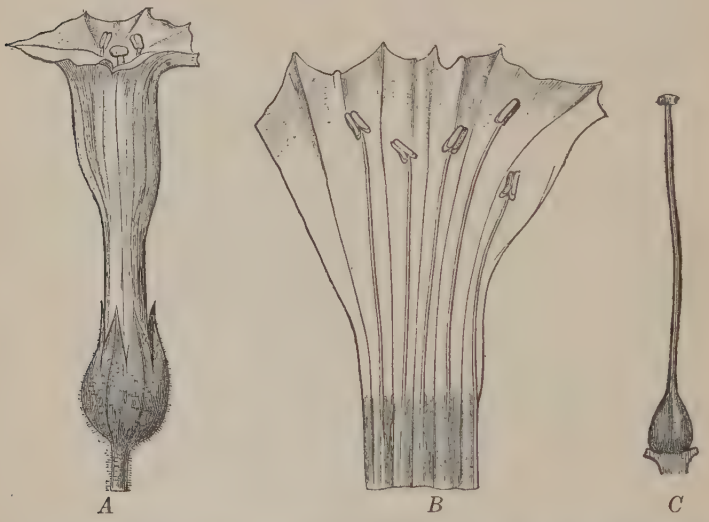


FIG. 102. — Flower of tobacco: *A*, sympetalous corolla; *B*, tube of corolla cut open and showing stamens; *C*, the pistil (carpels), showing ovary and style (the stigma forms the surface of the knob-like tip of the style). — After STRASBURGER.

the corolla may not be showy or even colored, both sets may be showy, neither set may be showy or colored, etc.

The general rôles played by calyx and corolla have to do with the sporophylls. The calyx protects the young and growing parts within while the flower is in bud. The showy corolla is related in some way to the visits of certain insects (as bees, butterflies, moths, etc.), which become agents in transporting pollen (pollination; see § 73, p. 125). This sub-

ject of the relation of insects to flowers is a very large one, and will be presented in the following chapter.

The great variation in the structure of the corolla is the variation of chief service in classification, so far as the perianth is concerned. A great many terms have been applied to the different conditions of the corolla, and a few of the most significant conditions are as follows. The simplest kind of corolla is one in which the petals are free from one another and are all alike. Such a corolla is said to be *polypetalous* (of " many petals ") and *regular*. In many flowers

FIG. 103. — Sympetalous flowers: *A*, bluebell; *B*, phlox; *C*, deadnettle; *D*, snapdragon; *E*, toadflax; *C*, *D*, *E* are irregular flowers (bilabiate in this case). — After GRAY.

the petals appear as if united to form tubes, bells, funnels, etc. (Figs. 102 and 103), and such a corolla is said to be *sympetalous* (" petals together "). This sympetalous condition is so constant in families of plants, that the highest one of the three great groups of Angiosperms is named the *Sympetalæ*, because in all of its families the flowers are sympetalous. In certain families the petals of a flower are not all alike; and then the corolla is said to be *irregular*. For example, the sweet pea and its allies have very irregular flowers, the petals being very much unlike, but the corolla is polypetalous. In the snapdragon, which is sympetalous, the rim of the tube has the appearance of two unequal lips,

three of the petals entering into the structure of the upper lip, and the other two petals forming the lower lip (Fig. 103, *C*, *D*, *E*). Such a corolla is naturally called *bilabiate* (" two-lipped "), and a large family of the Sympetalæ is called the *Labiatæ* (" lipped ") because its flowers have this two-lipped structure. These are simply conspicuous illustrations of irregular corollas.

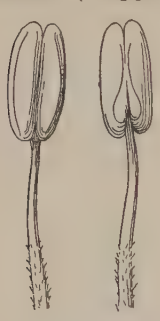


FIG. 104. — Two views of the same stamen, showing filament and anther, the latter appearing chiefly as two pollen sacs; the vertical line shown in the left pollen sac of the left stamen indicates the line along which the sac splits to discharge the pollen. — After SCHIMPER.

82. **The stamen.** — It was among the Angiosperms that the name stamen was given long ago to the sporophyll that bears microsporangia, and since it was recognized to be necessary to seed-formation, it was thought to be the male organ, and the pollen grains (microspores) it produced were thought to be male cells. It is evident that sporophylls and microspores belong to the sporophyte, a sexless individual, so that the stamen cannot be a male organ. The mistake was natural, because the minute gametophytes had not been discovered.

The stamens of Angiosperms vary extremely in appearance, but in most cases two distinct regions can be recognized (Fig. 104). There is a stalk-like region, which is long or short, slender or broad, called the *filament*, and a terminal region that bears the microsporangia, called the *anther*. The filament puts the anther in a favorable position for discharging its pollen grains, which are to be carried away by the wind or by insects or by some other agency.

The anther consists of the top of the sporophyll and usually four microsporangia, two on each side (Fig. 105). As the microsporangia grow, the two on each side usually run together and become one cavity (Fig. 106), so that in the mature anther there are usually two sacs (Fig. 104) containing pollen

grains (microspores). It is these sacs, usually consisting of two fused microsporangia, that are called *pollen-sacs* in

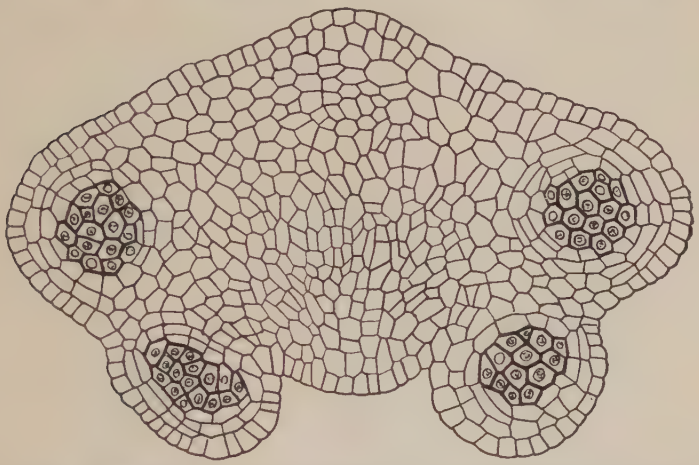


FIG. 105. — Cross-section of a very young anther of a lily, showing the four developing sporangia.

Angiosperms. A pollen-sac opens to discharge the pollen, usually by splitting down the line where the two microspo-

FIG. 106. — Cross-section of a mature anther of a lily (much larger than that shown in Fig. 105), showing the two chambers formed by the four sporangia, and also the region of opening for each chamber (*s*).

rangia come together (Fig. 104), but sometimes there is formed an opening (pore) at the top, which may even be extended into a tube (Fig. 107).

The stamens, like the petals and sepals, are not always free from one another, for sometimes the filaments appear as if they had been united. In some plants, for example,

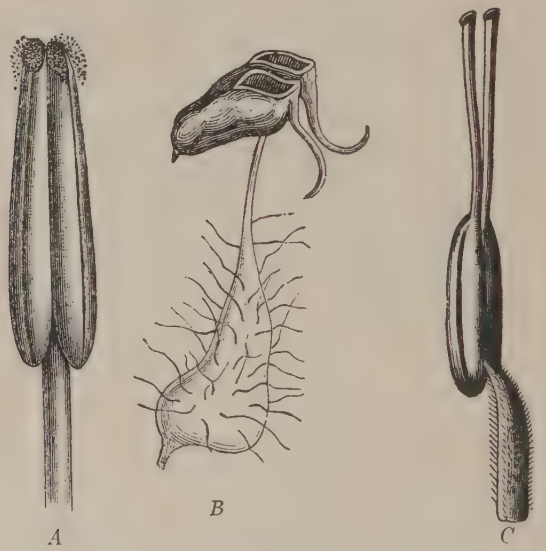


FIG. 107. — Anthers opening by terminal pores: *A*, potato or tomato; *B*, arbutus; *C*, cranberry or huckleberry. — *A* and *B* after ENGLER and PRANTL, *C* after KERNER.

the stamens appear united in this way in two or more sets, and sometimes they form a single set, all of the filaments together forming a tube (Fig. 108). In sympetalous corollas it is usual for the stamens to appear as if arising from the tube of the corolla (Fig. 102, *B*). This means that the petal set and stamen set have developed together, so that they are not distinct from one another at base.

While the two kinds of sporophylls (stamens and carpels) are usually associated in the same flower, there are many

Angiosperms whose flowers contain only one kind of sporophyll. This means that such plants have two kinds of flowers, one containing stamens, and the other containing carpels. These two kinds of flowers may be produced by the same plant or by different plants. In the latter case, there are two kinds of sporophytes, differing in their flowers, one kind bearing *staminate* flowers (with stamens only), and the other kind bearing *carpellate* flowers (with carpels only). For example,

FIG. 108. — Section of a flower of *Althæa*, showing sepals (*a*), petals (*b*), tube of stamens (*c*) inclosing the style (*d*), and also the ovules (*e*) within the ovary. — After BERG and SCHMIDT.

FIG. 109. — Indian corn (maize): *A*, showing the "tassel" (made up of staminate flowers); *B*, showing the ear (made up of carpellate flowers) within its husk and the exposed "silk" (made up of the long, protruding styles). — After DEVRIES.

the corn plant has the two kinds of flowers, but both are borne by the same individual (sporophyte), the staminate flowers forming the "tassel" and the carpellate flowers the "ear" (Fig. 109); while in the chestnut, one tree bears staminate flowers (and therefore does not produce chestnuts) and another tree bears the carpellate flowers.

83. **The carpel.** — It has been stated that the term "carpel" has been applied among Seed-plants to the structure called

megasporophyll among Pteridophytes; that is, the carpel is a megasporophyll. It has been stated also that the angiosperm carpel differs from that of the Gymnosperms in inclosing the megasporangia (ovules), the number inclosed ranging from one to very many.

In forming a case about the ovules, two regions of the carpel usually become evident (Figs. 102, *C*, and 110): (1) a more or less bulbous region that incloses the ovules (the *ovary*), and (2) a more or less extended beak-like region arising from the ovary (the *style*). The name ovary was given when the ovules were thought to be eggs, and both names are unfortunate, for they imply what is not true, but they have been used for so long a time that it would be more confusing to replace them than to retain them. The significance of the style is found in the fact that it provides a special receptive surface (the *stigma*) for the pollen grains, and the length and form of the style are answers to the problem of the most favorable position for the stigma. Very commonly the style swells into a knob at the top, and the surface of this knob is the stigmatic surface (Figs. 102, *C*, and 110, *C*). Sometimes the stigmatic surface extends down the side of a style, as in corn, in which the so-called "silk" is made up of styles (Figs. 109, and 110, *B*). Rarely, there is no style at all, and the stigmatic surface is upon the ovary itself. It is evident, therefore, that the two essential features of an

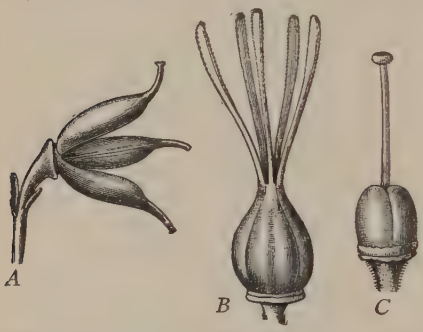


FIG. 110. — *A*, simple pistils (each one a single carpel); *B* and *C*, compound pistils (each one composed of several carpels); in *B* the stigma extends along the sides of the styles, in *C* it is on the terminal knob of the style. — After BERG and SCHMIDT.

angiosperm carpel are the ovary and the stigmatic surface, and that a style is generally present because it insures a more favorable position to the stigmatic surface for receiving the pollen.

A flower may have a single carpel, or it may have several. In the latter case, the carpels are arranged in one of two ways: (1) they may be distinct from one another (Fig. 110, *A*), or (2) they may be organized together in a single body (Fig. 110, *B* and *C*). It is convenient to have a term that may be applied to either situation, and that term is *pistil*.

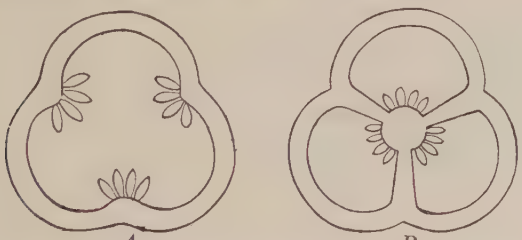


FIG. 111. — Cross-sections of ovaries of compound pistils: *A*, three carpels forming a "one-celled" ovary; *B*, three carpels forming a "three-celled" ovary. — After SCHIMPER.

A pistil is a single structure, with its ovary, style, and stigmatic surface, but it may consist of a single carpel or of two or more carpels organized together. These two conditions of the pistil are distinguished as *simple pistils* and *compound pistils* (often called *syncarpous pistils*, which means pistils with "carpels joined together"). The term pistil, therefore, is one of convenience rather than of exactness, for sometimes it is identical with carpel and sometimes it includes two or more carpels. It is like the word "house," which may include one room or two or more rooms. It follows that there are three possible carpel conditions in a flower: (1) a solitary carpel and therefore a single pistil; (2) two or more carpels forming as many pistils; and (3) two or more carpels forming a single pistil.

In the compound (syncarpous) pistil there are two different conditions of the ovary that must be mentioned. In the one case, the carpels are arranged so as to inclose a single cavity, as if open carpels had united edge to edge (Fig. 111, *A*). In the other case, the carpels are arranged so that there are as many cavities as there are carpels, as if closed carpels had come together, each with its own cavity (Fig. 111, *B*). These cavities within the ovary were long ago called "cells," and the inappropriateness of the term is evident. Therefore, some ovaries are said to be one-celled

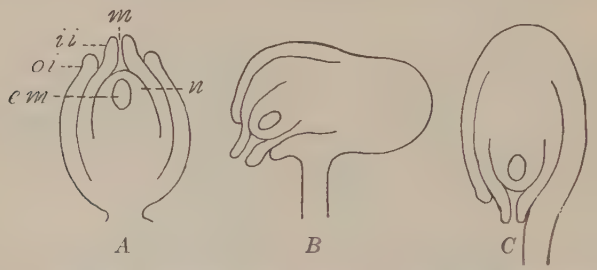


FIG. 112. — Sections of ovules, showing outer (*oi*) and inner (*ii*) integuments, micropyle (*m*), nucellus (*n*), and megaspore (*em*); in *B* the ovule is curved, and in *C* the stalk is curved, so that in both cases the micropyle is turned towards the wall of the ovary.

and some are two- or more-celled. It must be noticed that this does not correspond necessarily to the number of carpels, for although a simple pistil has a one-celled ovary, a compound (syncarpous) pistil may have either a one-celled ovary or a several-celled ovary.

84. **The ovule.** — The structure of the angiosperm ovule is essentially the same as that of the gymnosperm ovule. That is, there are one or two integuments investing the nucellus, whose tip is exposed at the micropyle (Fig. 112). In the midst of the nucellus the usually solitary megaspore appears, for, as in Gymnosperms, although several megaspores start, it is seldom that more than one develops to the full size and power.

The position of the ovule within the ovary cavity has certain features that must be noted. The ordinary entrance to the nucellus is through the micropyle, and therefore the position of the micropyle is important. In some cases, the ovule arises from the bottom of the ovary cavity (or near it) and grows directly away from the wall of the ovary, so that the micropyle is as far from the wall as it can be (Fig. 112, *A*), which is a relatively unfavorable position. In most Angiosperms, however, the ovule or its little stalk (*funiculus*) curves in growing, so that the micropyle is brought relatively near the wall of the ovary (Fig. 112, *B* and *C*). That this position is a favorable one is evident when it is understood that the pollen tube grows along the wall of the ovary and enters the ovule by way of the micropyle. In examining ovules it will be found that most of them are not straight, but are curved in various ways, and the curving means a more favorable relation of the micropyle to the entrance of the pollen tube.

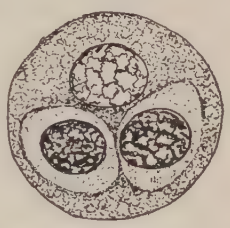


Fig. 113. — Pollen grain (microspore) containing the male gametophyte which consists of three cells or nuclei; the uppermost nucleus is the tube nucleus; the two cells, each containing a nucleus, are the sperms.

85. **The gametophytes.** — It was stated (§ 73, p.123) that among the Gymnosperms the male gametophyte is represented by a few cells developed by the microspore (pollen grain) and remaining within it, and the female gametophyte by a larger group of cells developed by the megaspore (within the ovule) and remaining within it. The same statements are true of the Angiosperms, and the gametophytes are still more reduced in the number of cells.

The male gametophyte (within the pollen grain) consists usually of three cells, often represented only by three nuclei (Fig. 113). One of them is the nucleus associated with the development of the pollen tube, and hence is called the *tube nucleus;* the other two are the sperms (represented either

by nuclei or naked cells). It would be hard to imagine a gametophyte reduced to lower terms, and it is not at all surprising that the pollen grain was thought to be the male cell, rather than a spore containing a male gametophyte. In fact, no one would have recognized these three cells or nuclei as a gametophyte, if the gametophytes of the Gymnosperms and the Pteridophytes had not been studied.

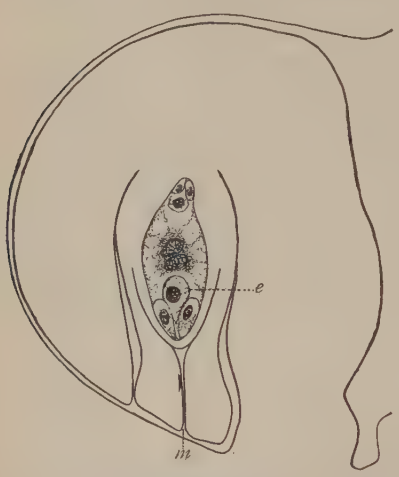


FIG. 114. — The female gametophyte of a lily, having developed within the megaspore, which is within the nucellus of the ovule; in the end of the embryo-sac (the name given to the megaspore when the gametophyte begins to develop) towards the micropyle (*m*) is a group of three cells, one of which is the egg (*e*); at the other end of the sac is another group of three cells; in the midst of the sac the two nuclei are seen which are to fuse and form the endosperm nucleus.

The female gametophyte (within the megaspore that is in the nucellus) at first consists usually of eight nuclei, which become arranged very definitely (Fig. 114). When the megaspore germinates to form the gametophyte, it ceases to be a spore, and is represented only by the encasing wall that surrounds the gametophyte. The cavity thus inclosed is called the *embryo-sac*. In other words, we speak of the megaspore until it begins to germinate, and then we call the same cavity an embryo-sac. This name was given before there was any knowledge of the existence of a megaspore or a female gametophyte within an ovule, for it was seen that the embryo appeared in a sac-like cavity. Within this embryo-sac three of the eight nuclei become placed in the end of the sac towards the micropyle, and are organized into

a group of three naked cells, one of which is the egg. Three other nuclei become placed at the other end of the sac, and may remain as free nuclei or become organized into a group of three cells. The two remaining nuclei behave in a remarkable way, for they come together and fuse to form a single large nucleus, which is called the *endosperm nucleus* because it produces the endosperm, a tissue developed within the embryo-sac to nourish the embryo. A female gametophyte ready for fertilization, therefore, consists of seven cells or nuclei (Fig. 114): a group of three at the end of the sac towards the micropyle, one of which is the egg; another group of three at the other end of the sac; and the large endosperm nucleus (two nuclei fused) lying between.

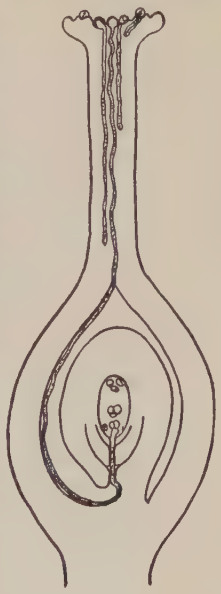


Fig. 115. — Diagram of pollen tubes penetrating the style (grains can be seen lying on the stigma); one of the tubes has passed through the style, entered the ovary cavity, passed along the wall of the ovary, entered the micropyle of the ovule, penetrated the tip of the nucellus, and discharged its two sperms into the embryo-sac; one of the sperms fuses with the egg, the other with the endosperm nucleus.

86. **Fertilization.** — The act of fertilization must be preceded by pollination, which is a notable feature of Angiosperms. Among Angiosperms there is a good deal of wind-pollination, but in addition to this there is a remarkable development of insect-pollination. So important and elaborate is this relation between the flowers of Angiosperms and insects that it will be discussed in the following chapter. At this point, all that is necessary to state is that through the agency of wind or of insects the pollen is carried from the stamens to the stigmatic surfaces of pistils, with of course much loss

of pollen by the way. This landing place of pollen in Angiosperms is very different from that in Gymnosperms. In the latter group the pollen reaches the tip of the nucellus, but in the former group it can reach only the surface of the carpel that incloses the ovules. This means that in Gymnosperms the male cells (in the pollen grain) are separated from the egg only by the tissue at the tip of the nucellus, while in Angiosperms the male cells are separated from the egg not only by the tissue at the tip of the nucellus, but also by the style and the ovary cavity.

After pollination has been accomplished, therefore, there must be an extensive development of the pollen tube before fertilization can be accomplished (Fig. 115). A good pollen grain lying on the stigmatic surface begins to send a tube into the style, and into the tip of the tube the two sperms pass. The growth of the tube is started by a sugary secretion of the stigmatic surface; it continues its growth down through the style by means of food material supplied by the adjacent cells, enters the ovary cavity, and grows along its wall, enters a favorably placed micropyle, reaches the tip of the nucellus, grows on through the tip of the nucellus, pierces the wall of the embryo-sac, and discharges its two sperms, which at last have free access to the egg.

Before fertilization is possible, therefore, there must be pollination and the growth of a pollen tube. It is strange that pollination and fertilization should ever be confused, when they are separated by such an extensive performance as the growth of the pollen tube. In some Angiosperms (and in many Gymnosperms) fertilization does not occur until a year after pollination, and the time interval varies in different plants between a year and a few hours.

A remarkable situation is developed in Angiosperms in connection with fertilization. Two sperms are discharged into the embryo-sac by the pollen tube, and there is only one egg. For a long time it was thought that one sperm united

with the egg, and that the other sperm simply wasted away, accomplishing nothing. Now it is known that while one sperm unites with the egg, the result being a fertilized egg, the other sperm unites with the endosperm nucleus, which then represents a case of triple fusion. This phenomenon of fertilization in the angiosperm embryo-sac has been called "double fertilization." The fertilized egg forms the embryo (the young sporophyte), and the fertilized endosperm nucleus forms the endosperm, a tissue that feeds the embryo.

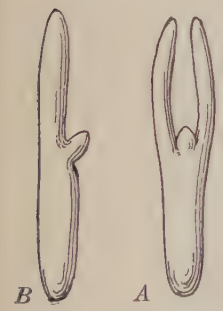


FIG. 116. — *A*, embryo of a Dicotyledon, showing the terminal stem tip between the two cotyledons (which therefore arise from the side of the embryo); *B*, an embryo of a Monocotyledon, showing the terminal cotyledon, and the stem tip arising on one side; in both cases the hypocotyl is the other (lower) end of the embryo.

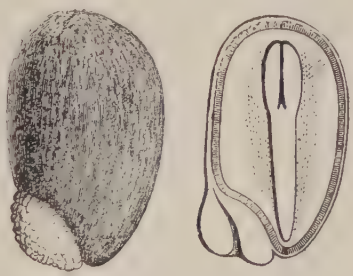


FIG. 117. — Seed of violet, the left figure showing the hard seed coat, and the right figure the abundant endosperm that surrounds the embryo; observe the regions of the embryo, namely, hypocotyl, two cotyledons, and a minute plumule (to form the stem with its leaves) between the bases of the cotyledons. — After BAILLON.

This double fertilization accounts for some things in connection with seeds that were not understood before. It means that the pollen parent can transmit its characters not only to the embryo, but also to the endosperm. For example, if corn with red ears be used as the pollen parent, and corn with white ears as the egg-producing parent, it would be natural to expect a mixture of white and red in the ears of the plant produced by the embryo. But the fact had long

been noted that the mixture of white and red also appeared in the very ears that had been pollinated, without waiting for the embryo to develop a new plant. This was a mystery until double fertilization was discovered, and it was found that the red color of the pollen parent was in the endosperm, and had been introduced by the sperm that fertilized the endosperm nucleus.

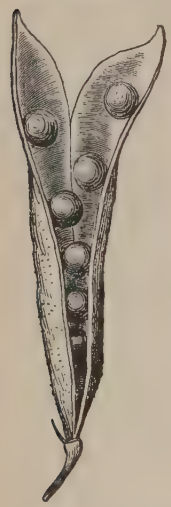


FIG. 118. — Pod of sweet pea bursting open to discharge its seeds. — After GRAY.

87. **The embryo.** — The fertilized egg develops the embryo, but in Angiosperms two distinct types of embryo are developed, which give names to the great groups of Angiosperms.

In one type of embryo, the tip of the hypocotyl (see § 75, p. 126), which is to give rise to the root, is at one end of the embryo, the stem tip is at the other end, and the cotyledons (see § 75), usually two in number, develop on the side of the embryo just below the stem tip (Fig. 116, *A*). The Angiosperms having this kind of an embryo are called *Dicotyledons*, and they are very much the more numerous group.

In the other type of embryo, the hypocotyl tip is at one end, the solitary cotyledon is at the other, and the stem tip develops on the side of the embryo (Fig. 116, *B*). The Angiosperms having this kind of embryo are called *Monocotyledons*.

It must not be supposed that the difference between Dicotyledons and Monocotyledons depends upon the number of cotyledons, as the names might imply, but on the relative position of the stem tip and cotyledon in the two cases. For example, a Dicotyledon, while it usually has two cotyledons, may have more, or it may have only one; but if the stem tip is terminal rather than lateral, it is a Dicotyledon. On the

other hand, a Monocotyledon is restricted to one cotyledon because it is a terminal structure, but it must be remembered that an embryo with one cotyledon may belong to a Dicotyledon.

88. **The seed.** — The features of a seed have been described under Gymnosperms (§ 76, p. 127), and they differ in no essential way among the Angiosperms. The embryo develops to a certain stage, varying widely in different plants, and then passes into the dormant stage, probably due in large measure to the cutting off of the water supply. During the development of the embryo the hard testa develops, protecting the delicate structures within against the exposures of an unfavorable season, as the cold of winter, dryness, etc. (Fig. 117).

Fig. 119. — Pod of iris ("three-celled") bursting open. — After Gray.

The seeds of Angiosperms differ widely as to the amount of endosperm left by the embryo when it becomes dormant. The endosperm in a seed, therefore, may vary from a great deal (Fig. 117) to none at all. For example, in the seeds ("grains") of cereals (wheat, corn, rice, etc.) a great amount of endosperm is left, and the world gets much of its food from this source; while in peas and beans no endosperm is left, but the cotyledons have stored up the food supply taken from the destroyed endosperm and have become bulky, so that in this case we use the cotyledons for food instead of the endosperm directly.

89. **The fruit.** — While the seeds of Angiosperms are ripening, changes take place also in structures outside the seed. For example, the ovary wall may change and become a hard or parchment-like seed-vessel, as in peas and beans, whose seed-vessels are called *pods* (Figs. 118 and 119). In other cases, the whole ovary may become a thin-skinned

pulpy mass in which the seeds are imbedded, as in the grape, currant, gooseberry, tomato, etc., all of which are *berries*. In still other cases, the ovary wall may ripen into two layers, the inner one being very hard and the outer one being fleshy, as in the peach, plum, cherry, etc., which are called *stone-fruits* (Fig. 120). Sometimes the changes extend beyond the ovary. For example, the cup-like base of the flower surrounding the ovary may become fleshy, as in the apple and pear, in which the ovary is represented by the "core" containing the seeds (Fig. 121). An extreme case is the pineapple, in which a whole flower cluster has become an enlarged fleshy mass, including the axis and the bracts (Fig. 122).

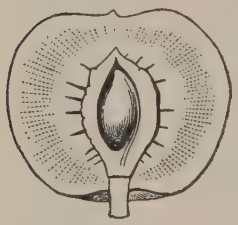


FIG. 120. — Section of a peach, showing pulp and stone formed as two layers of the ovary wall, and inclosing the seed (kernel). — After GRAY.

All of these changes outside the seed result in what is called the *fruit*. It is evident that "fruit" is a very indefinite thing. It may be dry or fleshy, and it may include only the ovary, or it may extend to the base of the flower, or it may involve a whole cluster of flowers.

90. **Summary.** — The Angiosperms are far more varied and abundant than are the Gymnosperms, and constitute the conspicuous vegetation of the land surface, and also the vegetation of greatest importance to man. Three features of the group stand out conspicuously in contrast with Gymnosperms.

The first feature is the inclosed ovule, the inclosing structure being the carpel. This means that the pollen grains, containing the male gametophytes, cannot reach the ovule, but are received by a special region of the surface of the carpel (the stigma). This means, further, that the pollen tube must traverse the style, enter the cavity of the ovary, reach the tip of an ovule (the position for the pollen grain in Gymno-

FIG. 121. — Longitudinal and cross-sections of an apple, showing the "five-celled" ovary (core) imbedded in the fleshy cup of the flower.

FIG. 122. — Pineapple, showing the whole flower cluster becoming a "fruit." — Photograph by LAND in Southern Mexico.

sperms), and then penetrate the tip of the ovule until the egg is reached.

The second feature is the appearance of the flower, which differs from a strobilus in having another set of members added to the sporophylls, and this set (perianth) is generally differentiated into sepals (calyx) and petals (corolla).

The third feature is related closely to the second, for it is the development of insect-pollination. Many Angiosperms retain the old method of wind-pollination, but insect-pollination is a conspicuous feature of the group, and it is associated with the remarkably diversified development of flowers.

In addition to these conspicuous features of Angiosperms, there are two others that should be remembered. The gametophytes are reduced to their lowest terms, and two kinds of embryo are formed (dicotyledonous and monocotyledonous).

CHAPTER IX

THE FLOWER AND INSECT-POLLINATION

91. **Evolution of the flower.** — Perhaps the most conspicuous feature of Angiosperms is the endless variety of flowers. In fact, the 130,000 different kinds of Angiosperms are largely distinguished by their flowers, which means that there are many thousands of different kinds of flowers. In an elementary book, therefore, it is possible to consider only flowers in general. We recognize the fact that flowers, starting with the strobilus condition, have changed in many directions, and it is not difficult to recognize some of the conspicuous directions. With these in mind, any flower examined will show to the observer the amount of progress it has made, and the general direction it has taken.

92. **Primitive flowers.** — If changes in flowers are to be noted, some starting point must be established. It is natural to suppose that the most primitive flowers are those nearest the strobilus condition. This means that the sporophylls (stamens and carpels) are numerous, arising from a more or less elongated axis; that they are entirely separate from one another; and that beneath them there arises the perianth that distinguishes a flower from a strobilus. This perianth consists of members that are entirely separate from one another, and these members are all alike, forming more or less of a rosette beneath or around the sporophylls. Probably in the most primitive flowers the perianth consisted of bract-like members, neither delicate in texture nor brightly colored.

It is from some such condition that the changes in flowers started, and the most conspicuous changes are indicated in the five following sections.

93. **The perianth.** — If the members of the perianth are all alike in primitive flowers, they have not remained so in most flowers. In general, they have become differentiated into two very different sets (Figs. 101 and 108), the calyx and the corolla (§ 81, p. 131). These sets differ not only in appearance, but also in the use to which they are put. The sepals (calyx) are usually leaf-like in texture and color, and protect the more delicate inner members while in the bud condition. The petals (corolla) are usually larger, more delicate in texture, and not green, their color being called the color of the flower. Such petals are associated in some way with the visits of insects, which will be considered later.

Almost every kind of exception to this general statement can be found. For example, in the lily, the members of the perianth are in two sets, but they are both petal-like in texture and color, so that they can be distinguished only by their relative positions (Fig. 123). In some flowers the petals have disappeared, and the sepals may have the color and texture of petals. Flowers without petals are said to be *apetalous* ("without petals").

In spite of exceptions that may obscure the fact, the most general tendency of flowers is to develop the perianth as two distinct sets of members.

94. **Definite numbers.** — In the more primitive flowers, the members are indefinite in number, for they are produced upon a more or less elongated axis, as in a strobilus. In the majority of flowers, however, this axis does not elongate, but remains short and generally broadens at the tip. In such cases, the flower members are produced upon this broadened tip (*receptacle*), and cannot be indefinite in number, for the space is limited. As a consequence, they appear in four circles, and each circle has a definite number of members.

It is remarkable how constant the numbers are in the two great groups of Angiosperms. In the Dicotyledons (§ 87, p. 146) with definite numbers, the prevailing number is five,

and a much less frequent number is four. In the Monocotyledons (§ 87) with definite numbers, the prevailing num-

FIG. 123. — Dogtooth violet (lily family), with parts of the perianth all alike, and hypogynous flowers.

ber is three. This fact is a convenience in recognizing these two groups without being compelled to examine the embryo.

For example, if the members of a flower are in sets of five or four, the plant is a Dicotyledon; if they are in sets of three, the plant is a Monocotyledon. This distinction does not hold in all cases, but it may be depended upon in the majority of the ordinary flowers.

It is very common for the stamen set to be doubled, so that the flower of a Dicotyledon may have five sepals, five petals, ten stamens, and five carpels; and the flower of a Monocotyledon may have three sepals, three petals, six stamens, and three carpels. On the other hand, in the most advanced families of Dicotyledons the carpels become reduced in number. For example, in the most advanced family of Angiosperms, and therefore the highest of all plants (the family to which sunflowers, goldenrods, asters, dandelions, etc., belong), the flower has five sepals, five petals, five stamens, and two carpels.

An important fact to notice is that all four members of a flower may not have advanced together, so that some of the members may have reached definite numbers, while the other members still have indefinite numbers. For example, the flower of the ordinary buttercup has five sepals and five petals, but it has an indefinite number of stamens and carpels. This is one of the facts that indicates that a buttercup is a much more primitive flower than an aster.

95. **United petals.** — It is a very general tendency in flowers for any set of members to develop altogether, and thus appear as if they had been united. It should be emphasized that they are not united in the sense that they ever were separate, but that developing all together, they appear as if they had been united. There are all degrees of this apparent union, from an appearance of union only at base to an appearance of union throughout.

It is so common for carpels to behave in this way, resulting in "compound pistils," that it seems rather exceptional when this is not the case (Fig. 110). Such behavior on the part

of the stamens is much less common (Fig. 108); and while it is much more common in the case of the sepals, it is quite irregular.

It is petals, however, that deserve special attention, for their growth in common or separately is a regular feature of great groups. The various forms that these so-called "united petals" assume are well known to all who notice flowers, as the funnel-shaped corolla of the morning glory, the bell-shaped corolla of the bell-flower, the nearly wheel-shaped corolla of the potato or tomato flower, the tubular corolla of the coral honeysuckle, etc. (Figs. 102 and 103). A corolla in this condition is called sympetalous (§ 81, p. 133). So constant a feature is it of the families in which it occurs, that it gives name to one of the two great groups of Dicotyledons, the *Sympetalæ*. The Sympetalæ include all the higher families of the Dicotyledons, and in distinction from them, all the Dicotyledons whose flowers are not sympetalous are called *Archichlamydeæ*, a name which means "primitive perianth," and is intended to include not only flowers that have the petals separate (polypetalous), but also those without petals and even without a perianth.

In this connection it may be pointed out that there are three great groups of Angiosperms to remember: the Monocotyledons and the two groups of Dicotyledons. They are very easy to distinguish ordinarily by their flowers, for if a flower has its members in threes, it is almost certain to belong to a Monocotyledon; if it has its members in fives or fours and its petals are separate, it belongs to the Archichlamydeæ; if the flower parts are in fives or fours and the corolla is sympetalous, it is one of the Sympetalæ.

96. **Union of two or more sets.** — Not only do the members of a single set often appear united in a flower, but two or more sets may grow together more or less completely. It has been mentioned (§ 82, p. 136) that in the case of sympetalous corollas it is usual to have the stamens develop in common with them.

so that they appear to grow from the tube of the corolla (Fig. 102). In the orchids, the stamen and carpel sets grow together so completely that they form a very unusual looking structure in the midst of the flower. The most important conditions of this kind, however, appear under the following definitions:

When the sepals, petals, and stamens all arise from underneath the pistil or pistils, so that one looks within the flower for the ovary (Figs. 101, 123, and 124, *A*), the flower is said to be *hypogynous* ("under the pistil"). When the three

A *B*

FIG. 124. — *A*, hypogynous flower (*Potentilla*); *B*, perigynous flower (apple). — After ENGLER and PRANTL.

outer sets grow together and form a cup-like structure about the pistil or pistils, and from the rim of this cup the sepals, petals, and stamens seem to arise, as in roses and apples (Fig. 124, *B*), the flower is said to be *perigynous* ("around the pistil"). When all four sets grow together in such a way that the sepals, petals, and stamens seem to arise from the top of the ovary, so that one looks beneath the flower for the ovary, as in amaryllis (Fig. 125) and iris (Fig. 127), the flower is said to be *epigynous* ("upon the pistil"). Hypogynous flowers represent the most primitive condition of the flower, while epigynous flowers are characteristic of all the higher families of Angiosperms.

97. **Irregularity.** — In some flowers the members of a set

are not all alike, and this tendency is chiefly noted in connection with the corolla. Attention has been called to the irregularity of such flowers as the sweet pea and the snapdragon (§ 81, p. 133), the two kinds of irregularity they represent being characteristic of certain large families (Fig. 103, *C*, *D*, and *E*). In addition to these, attention should be called to the irregularities called spurs (Fig. 103, *E*), which are conspicuous in orchids (Fig. 128), larkspurs, etc., and to sacs or pouches, such as appear in the lady slippers. These spurs and sacs are always associated with the secretion of nectar, for which many insects visit flowers.

Fig. 125. — Snowflake (amaryllis family), with epigynous flowers. — After Strasburger.

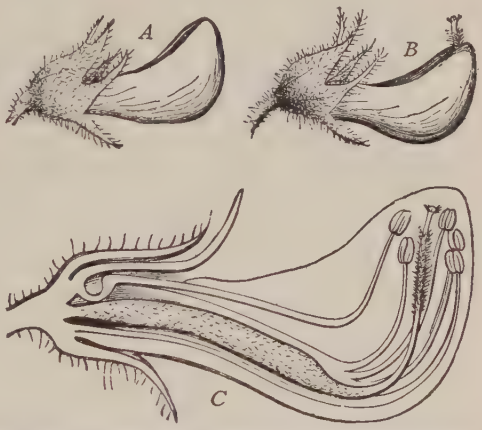


Fig. 126. — Rose acacia: *A*, keel projecting from calyx (the other petals removed); *B*, protrusion of tip of style when keel is depressed; *C*, section showing position of parts within the keel. — After Gray.

98. **General statement.** — In the preceding sections, the prominent departures from the condition of the primitive flower have been noted. It should be understood that these departures occur in all sorts of combinations, and it is the varying combinations that make the conspicuous differences among

flowers. A flower that has an indefinite number of members, and that is polypetalous, hypogynous, and regular, has a combination of characters that puts it low in the scale of Angiosperms. On the other hand, a flower with a definite number of members, and that is sympetalous, epigynous, and irregular, has a combination of characters that ranks it very high. By observing the combinations in the flower, the relative positions of the flowering plants may be estimated.

FIG. 127. — Longitudinal section of an iris flower, showing a stamen between the drooping petal and the petal-like style; the stigmatic shelf is seen at the top of the style above the stamen; the nectar pit is at the junction of petal and stamen; observe the section of the ovary, whose position shows that the flower is epigynous. — After GRAY.

99. **Pollination by insects.** — It has been stated (§ 86, p. 143) that the prevailing method of pollination among Angiosperms is the use of insects as the agents of transfer. The method of transfer by means of the wind, as among Gymnosperms and many Angiosperms, is wasteful, in the sense that there must be a great amount of pollen produced in order that a little of it may be sure to reach the right spots. When insects carry pollen directly from one plant to another, pollination becomes so definite a process that a comparatively small amount of pollen is sufficient to insure pollination.

The transfer of pollen from the stamen to the pistil of the same flower is called *self-pollination*, while transfer to the pistil of another flower is called *cross-pollination*. The

" other flower " may be upon the same plant or upon a different plant, but the cross-pollination that is significant is that which involves two distinct plants. Since flowers are very commonly arranged to secure cross-pollination, it must be of more advantage to plants in general than self-pollination.

This relation between flowers and insects is mutually helpful, for the flower secures pollination and the insect secures food. The food supplied by the flower is either *nectar*, a sweet secretion often wrongly called " honey," or pollen. The insects that visit flowers may be grouped as nectar-feeders, represented by moths and butterflies, and pollen-feeders, represented by bees and wasps. The presence of these supplies of food is made known to the insect by the display of color, by odor, or by form. Just what attracts different insects is not always clear, but color, odor, and characteristic forms belong to flowers visited by insects, so that it seems safe to conclude that by these features the insects recognize their feeding ground.

The relation between flowers and insects is most striking in those flowers arranged for cross-pollination. This arrangement involves both the hindrance of self-pollination and the securing of cross-pollination, and each kind of cross-pollinating flower has solved these problems in its own way. A few examples will be given, to suggest the kinds of arrangements to be looked for, but the student should examine as many cross-pollinating flowers as possible, and try to determine how self-pollination is hindered and how cross-pollination is secured.

In those plants that have staminate and pistillate flowers on different individuals, the case is clear, for self-pollination is effectually prevented by the absence of stamens from flowers with pistils. However, in such cases, the wind is as apt to be the agent of pollination as insects.

The most difficult situation is where stamens and pistils

are associated in the same flower, and the pollen is ready for shedding and the stigma ready to receive at the same time. In such a case nothing can prevent self-pollination except some mechanical hindrance that makes it unlikely that the pollen will reach the stigma. It is this situation that has resulted in many of the irregularities and striking forms of flowers, so that such flowers are among those most prized in cultivation. Three notable examples will serve as illustrations.

The sweet pea and its allies have what are called " butterfly-shaped " flowers. Two of the petals together form a boat-shaped structure (*keel*) which encloses the several stamens and the simple pistil (Fig. 126). The stigmatic surface is on the top of the style and projects beyond the anthers, whose shed pollen lodges on a hairy zone of the style below the stigma. The projecting keel is the natural landing place for a bee visiting the flower; and this keel is so attached that the weight of the insect depresses it. This depression of the keel causes the tip of the style to emerge and to strike the body of the insect. It is a glancing blow, so that after the tip has struck the insect, the surface of the style is also rubbed against its body, brushing the lodged pollen on to the insect. At the next flower visited, the stigma strikes the pollen brushed off in the previous flower, and then a new supply of pollen is brushed from the style. In this way, each flower visited receives pollen from the preceding one, and sends pollen to the next one. Of course, there are large elements of chance in such a performance, but certainly self-pollination is fairly well guarded against, and cross-pollination is very likely to be secured.

In the iris, often called " flag," each stamen is in a kind of pocket between a petal and a petal-like style (Fig. 127). The stigmatic surface is on the top of a flap or shelf which extends from the style as a roof over the pocket. With the stamen beneath this shelf and the stigmatic surface on top, it is clear

that self-pollination must be very unlikely. The nectar is in a little pit at the bottom of the pocket. As the insect crowds its way into the narrowing pocket, its body is dusted by the pollen; and when it visits the next flower, and pushes aside the stigmatic shelf, it is likely to deposit upon it some of the pollen obtained from a previously visited flower.

The orchids are most remarkable in their arrangement for insect-pollination. In fact, each kind of orchid is usually so adjusted to some particular kind of insect that no other insect can secure the nectar or carry off the pollen. There are two pollen sacs, and the pollen grains cling together in a mass, which is pulled out of the sac bodily. A common arrangement is as follows (Fig. 128). Each of the elongated pollen masses terminates below in a stalk that ends in a sticky disk or button, and between these two buttons there extends the concave stigmatic surface, at the bottom of which is the opening into the long tube-like spur containing the nectar. Such a flower is adjusted to the visits of a large moth, with a long sucking-tube (" proboscis ") that can reach the bottom

FIG. 128. — Flower of an orchid (*Habenaria*): *A*, complete flower, showing three broad sepals, three narrower petals (the lowest one forming the long lip and the much longer spur which extends to the bottom of the figure), two pollen-sacs, between which extends the concave stigmatic surface (at the bottom of which the opening to the spur is seen); *B*, more enlarged view of pollen-sacs with their sticky buttons and the stigmatic surface stretching between; *C*, a pollen-mass removed; *D*, a button enlarged. — After GRAY.

of the spur. As the moth thrusts its proboscis into the tube, its broad head (against the stigmatic surface) is pressed against the sticky button on each side, so that when it flies away these buttons stick to its head and the pollen masses are torn out. When the next flower is visited, and the head of the moth is pressed against the sticky stigmatic surface, the pollen masses from the previously visited flower are thrust against it and are left there.

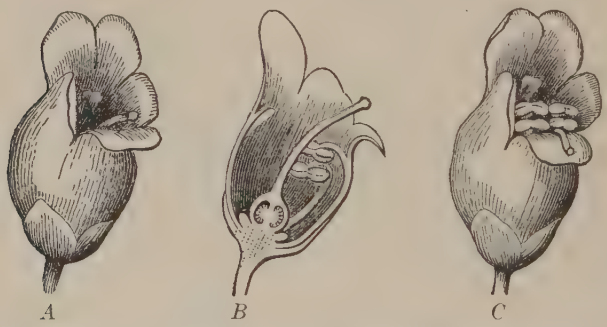


FIG. 129. — Flower of figwort (*Scrophularia*): *A*, stigma, in position to receive pollen; *B*, section of *A*, showing stamens curved back in tube of corolla; *C*, later condition, with style collapsed and stigma not in a condition to receive pollen, but the anthers brought up in position for shedding. — After GRAY.

A very common arrangement to prevent self-pollination in flowers containing both stamens and pistils is for the pollen and the stigma to mature at different times; that is, when the pollen is being shed, the stigma is not ready to receive; or when the stigma is ready to receive, the pollen is not ready to be shed. The two following examples will serve to illustrate.

When the flowers of the ordinary figwort open, the style bearing the stigma at its tip is found protruding from the urn-like flower, while the four stamens are curved down into the tube, and are not ready to shed their pollen (Fig. 129). At some later time, the style bearing the stigma wilts, and the stamens straighten up and protrude from the tube. In this

way, first the receptive stigma and afterward the shedding pollen sacs occupy the same position. A visiting insect will probably find flowers in both conditions, and in striking against protruding pollen sacs in some flowers and protruding stigmas in others, it carries pollen from one flower to another. In this case, the stigma is ready first; but it is more common for the pollen to be ready first, as in wild geraniums, willow herb (" fireweed "), etc. In the latter case, when the flower opens, the eight shedding stamens project prominently, while the style is sharply curved downward and backward,

FIG. 130. — Flower of willow herb (*Epilobium*): *A*, anthers in position for shedding and style curved downward; *B*, later condition, with anthers empty and stigmatic lobes of style in position for receiving pollen. — After GRAY.

carrying the stigmatic surface well out of the way (Fig. 130). Later, the stamens bend away and the style straightens up and exposes the stigma. The result of insect visits is the same as described for the figwort.

Still another arrangement is not very common, but none the less interesting. The stamens and pistils are together in the flower, but there are usually two forms of flowers. In the little plant called " innocents " or " bluets," for example (Fig. 131), one kind of flower has short stamens included in the tube, while the style is long and projecting. In the other kind of flower the stamens are long and projecting, while the style is short and included in the tube. There is some difference between the pollen produced by the long stamens

and that produced by the short stamens, for the pollen from the long stamens is more effective on the long styles than it is on the short ones, and *vice versa*. This means that the pollen of either kind of flower is not effective on the style of the same flower. The body of the visiting insect fills the tube of the small corolla and projects above it. In visiting both kinds of flowers, one region of the body receives a

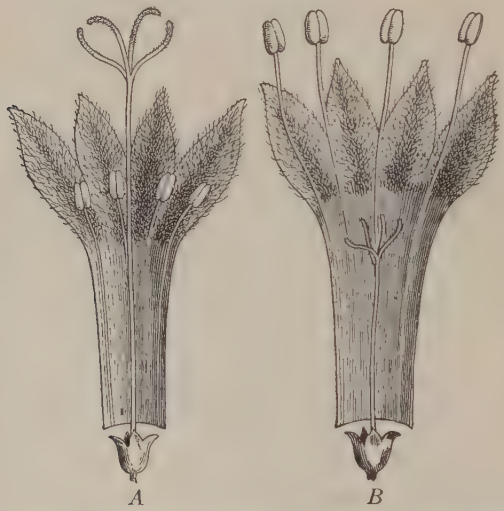


FIG. 131. — Flowers of innocence (*Houstonia*): *A*, form with short stamens and long style; *B*, form with long stamens and short style. — After GRAY.

band of pollen from the short stamens, and another region of the body receives a band of pollen from the long stamens. In this way the insect is soon carrying about two bands of pollen, which come in contact with the stigmas of the short styles and of the long styles.

100. **Pollination and plant-breeding.** — The purpose of practical plant-breeding is to improve the old races of useful plants and to produce new ones. In this work advantage is taken of pollination to produce certain results. Probably the

most common method of producing new and desirable forms is to "cross" two different kinds of plants; that is, to take the pollen of one kind and apply it to the stigma of another kind. This is artificial pollination, in the sense that the plant-breeder is the agent of transfer, but such crosses are occurring constantly in nature. The plant-breeder, however, makes a cross for a definite purpose, while crosses in nature are indefinite and matters of chance. The plant that is produced by crossing parent plants of different kinds is a *hybrid*. The purpose of the plant-breeder in producing hybrids is to get in a single plant a combination of desirable qualities belonging to the two parents. It must not be supposed that every hybrid shows the desired combination, for usually only one individual out of thousands will show it. For example, if a race of wheat is found to be very resistant to dry weather, this feature would be regarded as a very desirable one. This valuable "drought-resistant" character, however, might be associated with a grain of poor quality, so that this kind of wheat could not serve our purpose. One method of procedure in such a case would be to cross a wheat of good quality with the drought-resistant wheat, in the hope that among the hybrids thus produced, some one of them would have the desired combination of good quality and drought-resistance. If this could be the case, the desirable hybrid would be propagated, this time cross-pollination being guarded against, and the seed multiplied for use. The use of hybrids in plant-breeding, therefore, is to secure desired combinations of characters, and the securing of hybrids is by artificial pollination.

101. **Summary.**—The evolution of the flower has proceeded in many directions, but there are certain general tendencies that can be kept in mind. The perianth is generally differentiated into two sets, the sepals and the petals, and the latter usually constitute the conspicuous feature of the flower. There is also a tendency to shorten the receptacle, so that the num-

ber of each set is definite, the prevailing number of flower parts among Dicotyledons being five or four, and among Monocotyledons three. There is also a strong tendency for the members of any set to develop together so as to appear united. This is most common in the case of carpels, so that a pistil most frequently consists of more than one carpel, but it is most regular in the case of petals, characterizing one of the three great groups of Angiosperms (Sympetalæ). There is also a tendency for two or more sets to develop together so as to appear united, the extreme case being epigynous flowers, which are characteristic of the highest members of both Dicotyledons and Monocotyledons.

Many of the variations of the flower are associated with the visits of insects which feed upon the nectar or pollen of flowers and thus become the agents of cross-pollination. This relation between flowers and insects is often general, but it may be so special that only a particular kind of insect can act as the agent of pollination for a particular kind of flower (as among the orchids).

The use of artificial cross-pollination in plant-breeding is to secure hybrids that combine certain desirable qualities of two different kinds of parents, but the desired combination usually appears in an extremely small number of the hybrids produced.

CHAPTER X

DISPERSAL AND GERMINATION OF SEEDS

102. **The seed structures.** — There are three structures to be considered in connection with the seed (Fig. 117): (1) the *testa* (seed-coat), which is a hard and resistant protective structure; (2) the *endosperm*, which is the tissue usually containing stored food; and (3) the *embryo*, which is

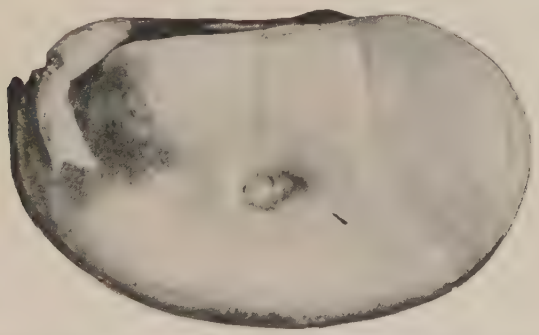


FIG. 132. — Section of bean with one cotyledon removed, showing the testa (the dark boundary), the remaining cotyledon (filling the seed to the testa), the hypocotyl (its tip directed upward), and the plumule (directed downward).

the young plant that is to be protected and fed, and which is to emerge from the seed and form a new and independent plant. The testa and the embryo are always evident, but sometimes the endosperm has disappeared. For example, in the cereals (wheat, corn, rice, etc.) all three structures are present, and the endosperm contains the starch we use for food; but in peas and beans the endosperm has disappeared.

having been consumed by the embryo, which occupies all the space of the seed within the testa (Fig. 132). The food we obtain from peas and beans, therefore, has been transferred from the endosperm to the embryo (chiefly to the cotyledons, which form the bulk of the embryo).

The embryo is in a dormant stage; that is, its protoplasts are inactive. With the embryos in this condition, the seeds are scattered, and may remain for a long time without showing any of the ordinary signs of life. If stored in a dry

FIG. 133. — Seed-vessel (fruit) of violet splitting into three "valves" and discharging its seeds. — After BAILLON.

FIG. 134. — Pods of a wild bean twisting in discharging seeds. — After BAILLON.

place, the period of dormancy may be very much prolonged, but in ordinary cultivated plants, the best results are obtained from seeds "planted" in the year following their formation. The danger in keeping seeds too long is that the embryos may deteriorate, and although the seeds look sound, the young plants may not be able to grow. It is for this reason that "seed-testing" has become a very important business, to learn whether seeds offered for sale are capable of "germination."

It is evident that seed-dispersal and seed-germination are the two important topics in connection with seeds in nature.

In cultivation, man cares for the " dispersal " when he plants seeds, but the germination must be left to nature.

103. **Seed-dispersal.** — It is a well-known fact that seeds usually are " scattered," which means that they are carried away from the parent plant. The advantage of seed-dispersal, as the scattering in nature is called, is so obvious that it needs no explanation. It is commonly said that the dispersal of seeds results in carrying them " beyond

FIG. 135. — Fruit (akene) of a dandelion with tufts of hair. — After KERNER.

FIG. 136. — Fruit of *Senecio* with tufts of hair. — After KERNER.

the reach of rivalry" with the parent plant. This is certainly true, but it probably carries them within the reach of rivalry with other plants. The safest thing to say is that seed-dispersal increases the chances for successful seed-germination. Seed-dispersal involves not only seeds, but very often fruits also. In those fruits that open to discharge their seeds, the seeds alone are carried; but when fruits do not open, the fruit itself is transported. The distances to which seeds or fruits are carried from the parent plants are exceedingly variable,

ranging from a very short distance to a very great distance, as the following illustrations will show.

Fig. 137. — Seed of milkweed with tuft of hair. — After Gray.

Fig. 138. — Seed of fireweed with tuft of hair.

In some plants there is a mechanical discharge of seeds provided for in the structure of the seed-vessel ("fruit"). For example, in the violet, when the seed-vessel splits, its walls press upon the seeds so that they are pinched out, as a moist apple-seed is projected by being pressed between the thumb and finger (Fig. 133). When the pod of the wild bean bursts, the two "valves" twist violently and throw the seeds (Fig. 134).

Fig. 139. — Winged fruit of maple. — After Kerner.

In the touch-me-not ("wild balsam") a strain is developed in the growing wall of the seed-vessel, so that at rupture, which may be brought about by a slight pressure, the pieces suddenly curl up and throw the seeds. This mechanical method may be regarded as the poorest of all the methods of dispersal, for at the very best a seed-vessel can discharge its seeds only a very short distance.

A more effective method of dispersal and a much more common one is by means of currents of air. This means that seeds or fruits must be very light, or that they must develop

Fig. 140. — Winged seed of *Bignonia* (a relative of catalpa). — After Strasburger.

special appendages to aid in their flight. Among the most common appendages are tufts of hair and what are very naturally called "wings." For example, plumes and tufts of hair are developed by the seed-like fruits of thistle and dandelion (Figs. 135 and 136), and by the seeds of milkweeds (Fig. 137) and fireweeds (Fig. 138); while wings are developed by the fruits of maples (Fig. 139) and elms, and by the seeds of catalpa (Fig. 140). An interesting modification of the wind-dispersing habit is exhibited by the "tumbleweeds" or "field rollers" of the western plains and other level stretches (Fig. 141). These plants are profusely branching annuals with a small root system in light or sandy soil. When the work of the season is over, and the rootlets have shrivelled,

the plant is easily broken from its roots by a gust of wind, and is trundled along the surface like a light wicker ball (Fig. 141), the ripe seed-vessels dropping their seeds by the way. Wind-dispersal is far more effective than mechanical discharge, but it is fitful, and its range usually is not very great. " Thistledown " may be floated into a neighboring field, and a strong wind may carry the comparatively heavy-winged fruits of the maple and elm some distance, but at best the scattering is only over a neighborhood.

Fig. 141. — A common tumbleweed.

A wide-ranging method of dispersal is by means of currents of water. For example, the banks and flood-plains of streams may receive seeds from a wide area, dependent upon the extent of the drainage system. Along the lower stretches of such rivers as the Mississippi, the Missouri, and the Ohio, almost every season new plants are added to those growing along the banks, and some of them may have come from great distances. This kind of distribution, therefore, may become almost continental in extent. Still more far-reaching is the

dispersal brought about by oceanic currents, both by waves carrying seeds along the coast, and also by the deeper currents that extend from continent to continent or to oceanic islands. It has been found that many seeds can endure even prolonged soaking in sea-water and then germinate. From a series of experiments, Darwin estimated that the seeds of at least fourteen per cent of the British plants can retain their vitality in sea-water for twenty-eight days. At the ordinary rate of oceanic currents, this period would permit seeds to be transported over a thousand miles.

FIG. 142. — Fruit (akene) of Spanish needles with barbed appendages. — After KERNER.

FIG. 143. — Fruit of beggar-ticks with barbed appendages. — After BEAL.

The dispersal of seeds by means of animals is a very common method, but it is accomplished in so many ways that only a very few illustrations can be given. Water birds are great carriers of seeds, which are contained in the mud clinging to their feet and legs. This mud from the borders of ponds is usually filled with seeds of various plants. Waterbirds are generally high and strong fliers, and the seeds may be transported in this way to the margins of distant ponds and lakes, and so become very widely dispersed. In many cases, seeds or fruits develop grappling appendages of various kinds, forming the various " burs " that lay hold of animals brushing past, and so the seeds become dispersed. Common illustrations of fruits with grappling appendages are Spanish needles (Fig. 142), beggar-ticks (Fig. 143), stickseeds, etc.;

and similar appendages are developed in connection with the bracts about the head of fruits of cocklebur and burdock (Fig. 144). Fleshy fruits are attractive as food to certain birds and mammals. Many of the seeds (such as those of grapes) are able to resist the attacks of the digestive fluids and escape from the alimentary tract in a condition to germinate.

104. **Conditions for germination.** — How long seeds may retain their vitality is a question that cannot be answered definitely, for it depends upon the kind of plant and also upon the conditions in which the seeds are kept. The stories of the germination of wheat obtained from the wrappings of Egyptian mummies have proved to be myths, but they are still in circulation. It was a common observation that when the original sod of the prairie was broken up in ploughing, plants often sprang up that seemed new to the region. Of course such plants came from seeds, and it is possible that they had been kept for a time in conditions unfavorable for germination until ploughing made the conditions favorable. But it must be remembered that seeds are scattered over wide areas every year, and that "new plants" may spring up on freshly ploughed ground whose seeds have never "waited" at all.

FIG. 144. — Heads of fruit of cocklebur (*A*) and burdock (*B*), showing grappling appendages of the bracts (involucre). — After KERNER.

Three conspicuous conditions for seed-germination are recognized; namely, moisture, a suitable temperature, and oxygen. When seeds are "planted," the soil is used as the most convenient source of continuous moisture; but of course seeds will germinate just as well on moist blotting paper or on moist sand. The soil has the great incidental

advantage in being available for other purposes after the seed has germinated and the young plant (seedling) has begun to manufacture its own food. The " suitable temperature " explains why seeds are not planted out of doors until the " ground has warmed up " a little. It is well known that plants vary widely in the amount of heat that is " suitable " for the germination of their seeds. For example, some seeds germinate in early spring or even on the melting snowfields of alpine and arctic regions, while others need tropical heat. The supply of oxygen necessary comes in the air, so that there must be free access of air. This explains why it is necessary to have the soil loose, so that there may be a free " circulation of air " through it. If the soil is flooded with water, so that there are no free passageways for air, seed-germination is interfered with in the same way that an air-breathing animal is interfered with if put under water. If these three conditions are supplied, and the seed is really a good one, it will germinate.

105. **The entrance of water.** — When a seed has been placed in the proper conditions for germination, the first visible result is its swelling on account of the entrance of water. It must be remembered that the protoplasts of the embryo and of the endosperm (if present) are in a dormant stage, and this stage is associated with a lack of water, so that the protoplasts are inactive (see § 10, p. 11). The entrance of water into the seed changes this dormant condition into an active condition. Figuratively speaking, the embryo, which has been " asleep," at least through one winter, " wakes up " and resumes its activity.

106. **Respiration.** — The superficial indication that the embryo has become active again is that oxygen enters the seed and carbon dioxide escapes from it, a gas exchange that indicates that respiration is going on (see § 31, p. 38). In other words, the embryo shows that it is alive and in an active condition by " breathing," which is a test of life that we apply

to animals as well as to plants. Not only does the germinating seed give off carbon dioxide, but also heat. This becomes very evident in the process of malting, in which a large mass of barley is put in germinating conditions in a confined space, and the total heat developed by the mass of germinating seeds is so great that the water may become scalding hot.

107. **Digestion.** — Before the embryo can grow, the food stored in the endosperm or in the embryo itself must be changed from its storage form to its transfer form; that is, from an insoluble form to a soluble form, so that it may move freely in solution. The process resulting in this change is called *digestion* (see § 30, p. 38). A very common storage form of food in seeds is starch, and by digestion the insoluble starch is converted into a soluble sugar. The active agents in this process are *enzymes*, substances produced by the protoplasts, and the particular enzyme that converts the starch of a seed into sugar is *diastase*. As a result of digestion, the seed, which had become swollen by the entrance of water, is observed to "soften." It is at this stage that the germination of the seed is checked in the process of malting, which thus secures the carbohydrates of the seed in the form of a solution of sugar.

108. **Assimilation.** — After digestion, the food in solution moves toward the active cells (protoplasts) of the embryo, in proportion to their activity. Growth is not uniform in amount throughout the embryo, so that some regions receive more food supply than others. The most actively growing region of the embryo at first is the hypocotyl (see § 75, p. 126), and in its cells the protoplasts are most active. The protoplasts use the food received by transforming it, step by step, into living protoplasm, and it is this process that is called *assimilation* (see § 30, p. 38). The protoplasmic body of the protoplast is used up in providing the materials for growth, and therefore it must be built up continually by assimilation.

109. **Food-storage.** — Thus far, only the carbohydrate starch has been mentioned as a food-storage form in seeds, and it is the most common form in the seeds used for food by men. But another conspicuous group of foods are the proteins (see § 29, p. 37), and carbohydrates are used in the manufacture of proteins before protoplasm can be reached. In some seeds proteins are stored in the form of little grains (*aleurone grains*). For example, in a "grain" of wheat (or of any ordinary cereal), the outer layer of endosperm cells contains aleurone grains, and the other endosperm cells contain starch grains. In some seeds, food is stored in the form of *fats* in liquid form (*oils*). Fats contain the same chemical elements (carbon, hydrogen, and oxygen) as do the carbohydrates, but not in the same proportion. Well-known oils obtained from seeds are castor-oil, linseed oil (from flax), cottonseed oil, and olive oil.

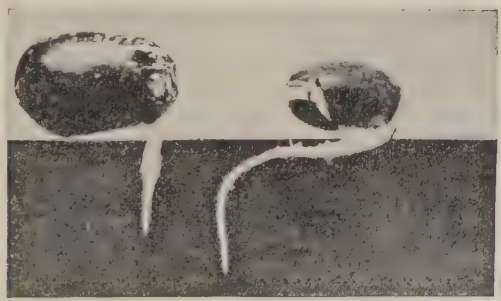


FIG. 145. — Germinating beans, showing the hypocotyl; the bean to the left has not been moved; the one to the right was turned 90° after it had reached the stage of the other, and has developed a curve in response to the stimulus of gravity.

110. **Escape of the hypocotyl.** — All of the processes described above as connected with germination are preliminary to the emergence of any part of the embryo from the seed. It was stated that growth is most active at first in the hypocotyl, whose tip is always directed towards that point in the seed-coat where the micropyle of the ovule was situated, and

which is still called micropyle in the seed. It is no longer an open "little gate," for it has been closed up during the formation of the testa, but it remains the easiest point of exit through the testa. Growth consists of cell-division followed by cell-enlargement. If the cells of the hypocotyl all divide and then each new cell enlarges to the size of the parent cell, the result would be a hypocotyl twice as long and twice as thick. Growth, however, does not proceed so uni-

FIG. 146. — A germination series of the garden bean, showing roots developing from the tip of the hypocotyl, the hypocotyl arch (pulling out cotyledons and plumule), and the straightening of the hypocotyl.

formly as this throughout a whole structure, and the most obvious result of this early growth of the hypocotyl is its rapid elongation. This elongation speedily brings the tip of the hypocotyl against the micropyle, and then through it, so that the first sign of the embryo outside of the seed is the emerging tip of the hypocotyl.

As the hypocotyl continues to elongate, it will be observed to curve towards the earth, unless it emerged from the seed in that direction (Fig. 145). This curvature is a *response* by the hypocotyl to surrounding influences (*stimuli*), and

sensitiveness to stimuli is called *irritability*. The hypocotyl is a very irritable structure, and conspicuous among the stimuli to which it responds are gravity and moisture.

111. **Geotropism.** — This word means "earth-turning," and it implies that there is a turning (curving) in response to the influence of gravity. It should be understood that geotropism is not the "influence of gravity," as is sometimes stated, but it is the response of the plant to the stimulus of gravity. If the hypocotyl, when it emerges from the seed, is directed upwards or horizontally, gravity acts as a stimulus and the irritable hypocotyl responds by developing a curvature that directs it downwards. The stimulus of gravity, therefore, results in directing the tip of the hypocotyl towards the soil and in keeping it in that direction (Fig. 145).

FIG. 147. — Germination of scarlet-runner bean: first stage of series shown in Fig. 148; one cotyledon removed to show the arch developed by the first joint of the stem, the stem-tip and leaves thus being freed, and the cotyledons remaining within the testa.

This is only one way of responding to the stimulus of gravity, for a stem usually responds by curving away from the earth and by maintaining this direction. These two kinds of response are distinguished by speaking of the hypocotyl as *positively geotropic* (its direction being towards the source of the stimulus), and of the stem as *negatively geotropic* (its direction being directly away from the source of the stimulus). Even these two directions do not include all of the responses to gravity, for branches of roots and of stems

are very commonly directed horizontally, so that they are neither positively nor negatively geotropic.

112. **Hydrotropism.** — This word means "water-turning," and it implies that there may be a curvature in response to the influence of moisture. The hypocotyl is sensitive to moisture and is *positively hydrotropic.* Since ordinarily the stimuli of moisture and gravity act upon the hypocotyl

FIG. 148. — Germination of scarlet-runner bean, the series following the stage shown in Fig. 147; the elongating first joint of the stem frees the stem-tip and leaves and finally straightens; the cotyledons remain within the seed coat.

from the same general direction, they coöperate in the result, but experiments can be devised to make them contradictory.

113. **Development of roots.** — When the hypocotyl penetrates the soil under the joint directive influence of gravity and water, the root system begins to develop from its tip (Fig. 146). In some cases the root continues the direction of the hypocotyl, being positively geotropic, resulting in what is called a *tap-root;* in other cases it branches at once in every direction, and is not at all positively geotropic in its responses. In any event, so far as seed-germination goes, the root an-

chors the seedling and establishes a grip on the soil that is necessary for the next events.

114. **Escape of cotyledons and plumule.** — After the root with its branches has anchored the seedling in the soil, the hypocotyl continues to elongate rapidly. Since it is anchored

FIG. 149. — Seedling of castor-bean, showing the large and green cotyledons.

now at both ends, one end in the seed and the other in the soil, elongation expresses itself in the development of an arch, the *hypocotyl arch*, which may be observed very easily in germinating beans (Fig. 146). The bent hypocotyl is in a state of tension, like a bent spring, ready to straighten as soon as it becomes free. This develops a pull on the cotyledons and plumule within the seed, and upon the roots in the soil. The

root anchorage holds and the cotyledons are pulled out of the seed-coat, and when they are free from it the hypocotyl straightens. The significant fact in this escape is not that the cotyledons are pulled out, for in many seeds they remain within the seed-coat, but that the plumule is pulled out, for it develops the stem and leaves.

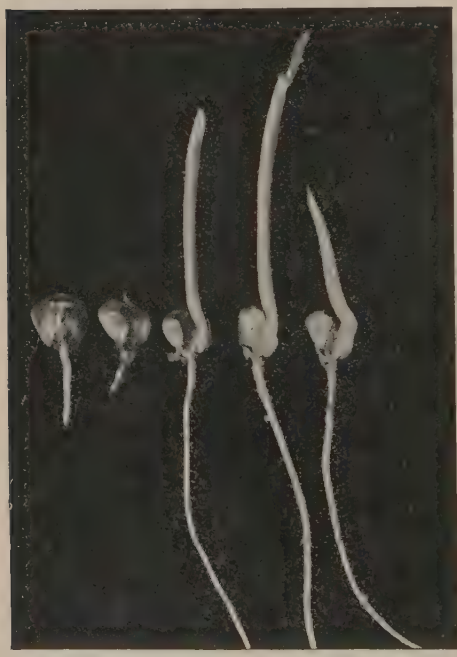


FIG. 150. — Germination of corn, showing superficial position of embryo, the unfolding leaves, and the roots; the single cotyledon is not seen, remaining in close contact with the endosperm.

This is only one method by which the plumule becomes free, but it is a common way, and will suggest the interpretation of other methods that ought to be observed. For example, in the scarlet-runner bean the cotyledons are not usually freed from the testa, the first joint of the stem (in the plumule) developing the arch and freeing the stem-tip and leaves, as may be seen in the series shown in Figs. 147 and 148. Such seeds as those of peas, castor-bean, squash, and corn should be germinated to show important variations. In the pea and acorn, for example, the cotyledons are gorged with food and are never freed from the testa, but the plumule is liberated by the elongation of the bases of the cotyledons

into stalks of varying lengths. In the castor-bean (Fig. 149) and squash, the cotyledons not only escape, but become green and work like ordinary leaves. In corn, as in all cereals, the embryo lies close against one side of the seed, so that it becomes completely exposed by the splitting of the thin skin that covers it (Fig. 150). In this case the single cotyledon is never freely expanded, but remains as an absorbing organ in contact with the starch-containing endosperm.

With the establishment of roots in the soil and the exposure of green leaves to light and air, germination is over, for the young plant is now able to make its own food.

115. **Phototropism.** — The stem of the seedling is sensitive to the direction of rays of light, and therefore it is said to be

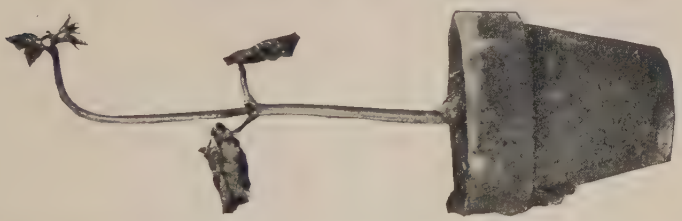


FIG. 151. — A bean seedling that was placed in a horizontal position and after two hours photographed.

phototropic ("light-turning"). It is not light in general that acts as a stimulus, but the *direction* of the rays of light. The response of the stem to this stimulus is to curve directly towards the source of the light rays, and therefore it is *positively phototropic.* Figure 151 shows a bean seedling placed in a horizontal position and after two hours photographed; while Figure 152 shows the same seedling completely inverted and photographed after two days.

The root is also phototropic, turning directly away from the source of light; that is, it is *negatively phototropic.* Figure 153 shows a seedling of a white mustard so arranged that both stem and root are exposed only to weak light, the

former showing positive and the latter negative phototropism, as explained more fully in the legend.

By putting together the results of the various *tropisms*, it is evident that an irritable structure (as a growing stem or root) responds to several of them at the same time. The tap-root, for example, has been shown to respond to the stimulus of gravity, of moisture, and of light, and each response directs it into the soil, so that its direction is determined by the sum of all these stimuli. In the same way, the stem is not only positively phototropic, but also negatively geotropic, so

Fig. 152. — The same seedling shown in Fig. 151, completely inverted, and after two days photographed.

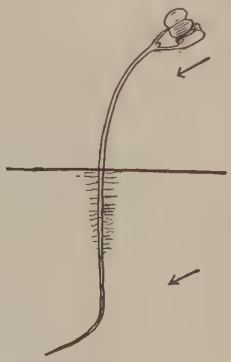


Fig. 153. — Seedling of white mustard grown in water and exposed to weak light, showing that the stem is positively phototropic and the root negatively phototropic; the arrows indicate the direction of the rays of light.

that the sum of these stimuli determines the direction away from the soil.

It was stated that all roots are not positively geotropic, for root branches frequently grow horizontally. In the same

way, all structures of the stem are not positively phototropic, for many branches grow horizontally, and leaf blades are very commonly horizontal. When it is remembered, however, that groups of stimuli act on organs, and that not all of them may be influencing the organ in the same direction, it will be understood that the actual direction is a resultant and not necessarily the direction that would be determined by any stimulus acting alone.

It should be kept in mind that stimuli which influence direction call forth an evident response only when the organ is out of line, and the response (*reaction*) is a curve that brings it back into line. The sensitive or irritable region of an organ is not necessarily the region where the reaction occurs; for example, the root tip is the sensitive region that " perceives " the stimulus, but the reaction appears in a curve at some distance from the tip. Nor does the reaction follow the stimulation immediately, for there is an interval, known as *reaction time*, which is generally much longer in plants than in animals. The reaction may be several hours, but in some cases it may be very short, as the movement of the leaves of the sensitive plant (§ 125, p. 213), and the snapping shut of the leaves of *Dionæa* (§ 127, p. 222).

116. **The hypocotyl.** — Any study of the germination of the seed impresses the fact that the hypocotyl is the most important organ. It is distinctly an organ of the embryo, for its work is over when germination has been completed. Its importance lies in the fact that it relates the seedling effectively to its surroundings, that is, it " orients " the seedling. It puts the root in the soil and it often liberates the plumule so that the stem may begin to develop its succession of leaves in relation to air and light. When the seedling has thus been started in the right directions, the hypocotyl disappears as a distinct structure, and the plant body consists of root, stem, and leaves.

117. **Summary.** — The chances of the successful germina-

tion of seeds are increased by dispersing them, and this dispersal is provided for in various ways. Some seeds are discharged mechanically; many seeds (or fruits) are equipped with tufts of hair (plumes) or wings for air-dispersal; many seeds (or fruits) are carried by currents of water, and in the case of oceanic currents they may be carried great distances; and many seeds (or fruits) are carried away from the parent plant by animals. It must be remembered, however, that many seeds and fruits fall to the ground from the parent plant and are not dispersed at all.

The process called seed-germination extends from the starting of a dormant embryo into activity to the beginning of food manufacture by the young seedling. The conditions necessary for germination are moisture, free access of air (oxygen), and a suitable temperature, and for most plants this combination is best secured by burial in loose soil. The entrance of water enables the dormant protoplasts to become active again, and this activity is evidenced by respiration. The first result of activity is the digestion of stored food which then passes into the active protoplasts and becomes assimilated. As a result, the growth of the embryo begins, the tip of the hypocotyl emerges from the seed, the root is established, the plumule (and often the cotyledons) are pulled out of the seed-coat, and when the seedling begins to manufacture its own food, germination is over.

CHAPTER XI

LEAVES

118. **General features.** — It is not necessary to define what is meant by foliage leaves, for no structure of plants is more familiar. They are thought of by botanists as expansions of green tissue exposed to light and air, and especially concerned in the manufacture of food. Everything important connected with a foliage leaf is to be explained by this fact, for arrangement, position, form, and structure are all related to the work of food manufacture. A consideration of leaves has been deferred until the Angiosperms can be included, for it is in this great group that the largest display of leaves is found.

The variation in the form and structure of leaves is so great that they are useful in classification, and for this reason numerous technical terms have been devised to indicate these variations with precision. However, to learn the definitions of all these terms is not to know a leaf and its work, and therefore in this presentation they are disregarded except so far as some of them may be of service.

119. **General structure.** — It is a matter of common observation that the green expansion called a leaf may arise either directly from the stem or it may have a stalk of its own (*petiole*). The presence or absence of a petiole (Fig. 154) is related to the exposure of the leaf, and has nothing to do with the structure of the leaf for the work of food manufacture.

If the leaf is examined superficially, it will be seen that

through the green tissue there extend " veins " (Fig. 154), as described in § 55 (p. 90). These veins are extensions of the vascular system, and carry water to the green tissue. It is necessary, therefore, that the veins branch sufficiently to reach all the working cells. How completely this is accomplished may be seen in a " skeletonized " leaf, from which all the green tissue has been removed, and only the veins

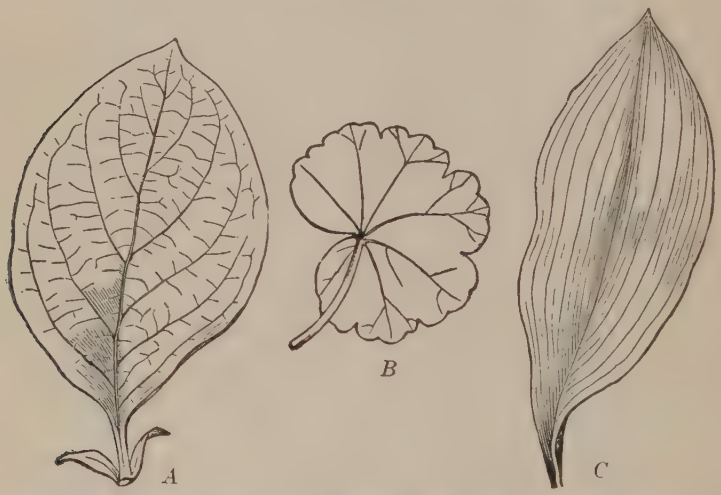


FIG. 154. — *A*, pinnate leaf of quince, which is entire and has a short petiole; *B*, palmate leaf of geranium, which is lobed and has a long petiole; *C*, parallel-veined leaf of lily-of-the-valley. — After GRAY.

remain (Fig. 155). Incidentally, but very necessarily, the vein system forms a stiff framework to support the expanded green tissue, which otherwise would collapse. That the veins are not the only mechanical support is evident when a leaf wilts, a thing which, as every one knows, is due to a lack of water. For an ordinary foliage leaf to keep its expanded form, the working cells must be gorged with water, and much of the stiffness of a broad leaf is due to this turgor (§ 10, p. 10) of the cells. The green tissue, therefore, is kept spread

out not only by the framework of the water-conducting vessels, but also by the turgor of its cells.

The general shape of a leaf is largely determined by the character of its vein system, and although the kinds of vein systems are numerous, the three most common ones may be noted. In one kind, a large main vein runs through the center of the leaf, and smaller veins arise from it on either side, branching in turn (Fig. 154, *A*). For convenience, the large main veins are called *ribs*, and the solitary central rib in the case just described is called a *midrib*. Leaves with midribs are called *pinnate*, because the vein system is like a feather, with its central shaft and branches, and such leaves are apt to be comparatively narrow and elongated. In another kind of vein system several ribs of equal prominence start out at the base of the leaf and diverge more or less widely, each giving rise to branches (Fig. 154, *B*). Such leaves are called *palmate*, because the ribs suggest the spread fingers arising from the palm of the hand, and they are apt to be broad and comparatively short. In a third kind of vein system there are no especially prominent ribs, but the veins run approximately parallel through the leaf from base to apex (Fig. 154, *C*). These "parallel" veins are not the only veins, but the branches ("veinlets") that arise from them are so small that they are not visible to ordinary observation. Such leaves are said to be *parallel-veined*, and they are always comparatively narrow and elongated, as in lilies and grasses.

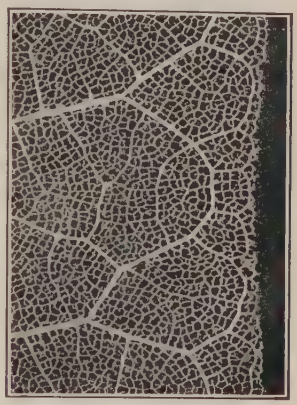


FIG. 155. — Portion of a skeletonized leaf (*Ficus*), showing the network of veins, and also the free endings of veins (open system).

The pinnate and palmate leaves are often called *net-veined* leaves, to distinguish them from the parallel-veined leaves, but really they are all net-veined leaves, the difference being that in pinnate and palmate leaves the network of veins is visible, while in parallel-veined leaves it is invisible. It is a common statement that Dicotyledons have pinnate and palmate leaves, while Monocotyledons have parallel-veined leaves. This is generally true of Angiosperms that grow in temperate regions, but when tropical plants are included, the distinction vanishes, for the banana has good pinnate leaves and the palm leaf used for "palm leaf fans" is palmate, and both of these plants are Monocotyledons. The real leaf distinction between Monocotyledons and Dicotyledons is that in Dicotyledons the veinlets end freely in the margin of the leaf (as well as elsewhere), forming an "open system" of veins (Fig. 155); while in Monocotyledons the veinlets do not end freely, but are all part of a "closed system."

FIG. 156. — Compound (branching) leaves: *A*, pinnately compound leaf of black locust; *B*, palmately compound leaf of red clover.

One of the notable differences among leaves is that the margins of some of them are variously toothed or lobed, while in others they are not. In the latter case the leaf is said to be *entire* (Fig. 154, *A* and *C*). Leaves with a closed system of veins are always entire, which means that most of the Monocotyledons have entire leaves. Leaves with an

open system of veins may be entire, but often develop a toothed margin in connection with the free endings of the vein system, which means that toothed and lobed leaves (Fig. 154, *B*) are characteristic of Dicotyledons. Leaves with an open system of veins may not only become toothed or lobed, but the lobing may be carried so far that the blade becomes discontinuous (Fig. 156), and appears as if broken up into several blades (*leaflets*). Such leaves are said to be *compound*, but they are better called *branching leaves*. The results of this branching habit of leaves are related to the character of the vein-system. In pinnate leaves with open venation, branching may result in elongated forms with very numerous leaflets; while in palmate leaves with open venation, branching results in broad forms and a more restricted number of leaflets. This difference and the reason for it become very evident when the pinnately branching leaf of black locust (Fig. 156, *A*) is compared with the palmately branching leaf of red clover (Fig. 156, *B*). Of course the branches in each case may branch again, and thus the leaf may become quite extensive, with very numerous leaflets. The most familiar illustrations are probably the extensively branching leaves of many ferns.

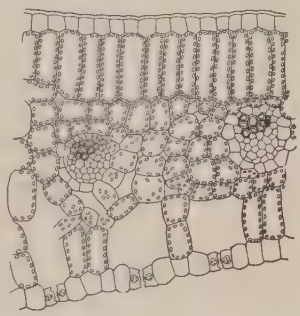


FIG. 157. — Cross-section of a lily leaf, showing the epidermis above and below, with three stomata in the lower epidermis; between the epidermal layers the mesophyll (the cells containing chloroplasts), with a layer of palisade cells against the upper epidermis, and below this the spongy tissue with air-spaces of various sizes (the stomata open into three large ones); imbedded in the mesophyll are sections of two veinlets, the group of xylem vessels (water-conducting) being at the upper side of each veinlet.

120. **Internal structure.** — The foliage leaf is a very efficient machine, and it is necessary to understand the general arrangement of its cells. To observe this most easily, thin

sections through some relatively thick, spongy leaf, like that of hyacinth or of lily, should be made. In such sections even a low power of the microscope will show three distinct regions (Fig. 157).

(1) *Epidermis.* — Bounding each side of the leaf is a layer of cells fitting closely together and usually without chloroplasts (Fig. 157). This is the *epidermis*, which is like a layer of water-proof material preventing excessive loss of water from the working cells within. The resistance to the escape of water is much increased by a substance formed on the outer walls of the epidermal cells, known as *cutin*, which forms a covering of the epidermis called *cuticle*. This layer of

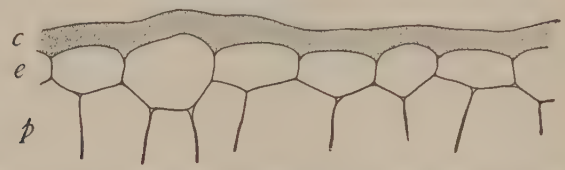


FIG. 158. — Section through a small portion of a yew leaf, showing the epidermis (*e*) with its thick cuticle (*c*), and the upper part of the palisade layer (*p*).

cuticle makes the outer epidermal walls look thick, and the thicker it is the more resistant is the leaf to the loss of water (Fig. 158). In plants of dry regions the cuticle may become excessively thick. An epidermis overlaid by cuticle forms not only a water-tight layer, but also an air-tight one. It is evident that the cells at work in food manufacture cannot be shut off from the air, for there must be an intake of carbon dioxide and an outgo of oxygen. For this reason, there is developed in the epidermis a set of guarded openings, the *stomata* (singular *stoma*).

The general outline of a stoma may be seen by peeling off the epidermis and examining it in surface view rather than in section (Fig. 159). In surface view it appears as two crescentic epidermal cells forming between them a slit-

like opening. These cells are called *guard-cells*, because they regulate the size of the opening. When seen in the cross-section of the epidermis, the stomata appear as pairs of small cells interrupting the epidermal layer (Fig. 157). The guard-cells usually project toward one another near the centre of their depth, so that the opening between them funnels down to a narrow slit and then enlarges, on the general plan of an hour-glass. The guard-cells can change their shape, and so enlarge or diminish the opening between them. It

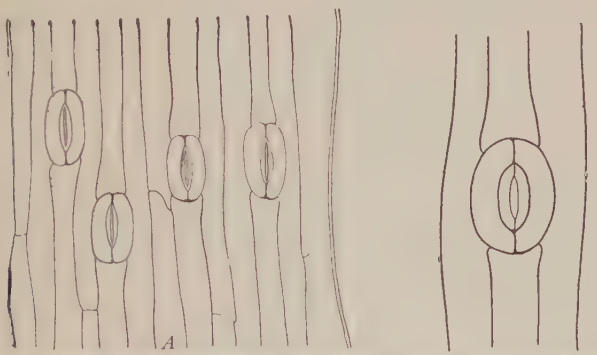


FIG. 159. — Surface view of epidermis of a hyacinth leaf: *A*, elongated epidermal cells and four stomata with their guard-cells; *B*, enlarged view of a single stoma.

is the stomata that provide passageways into the interior of the leaf, solving the problem of the epidermis how to prevent excessive loss of water and at the same time maintain communication with the air.

The number of stomata is a very important feature of the mechanism of a leaf, for it is found that very numerous small openings over a given area are as effective in gas exchanges as if the whole area were open. A fair average number of stomata is about 100 to each square millimeter of surface (about 62,500 to the square inch); and in some cases the number may reach 700 to the square millimeter (almost 450,000 to the square inch). When it is remembered that

stomata are to permit communication with the air without permitting an excessive loss of water, their distribution becomes a matter of course. For example, in horizontal leaves, the stomata are chiefly and sometimes exclusively on the under, more shaded, surface, a surface less dangerous to open to the drying air than the upper surface; on erect leaves (as iris), in which both surfaces are exposed alike to the light, the stomata are equally distributed; in floating leaves (as water-lilies) the stomata are naturally all on the upper surface; while in submerged leaves there are no stomata at all. Stomata are not peculiar to the epidermis of leaves, for they are found in the epidermis of any green part, as young stems, fruit, etc., and even on the petals of flowers.

(2) *Mesophyll.* — Between the two epidermal layers is the mass of green tissue making up the body of the leaf (Fig. 157), and called *mesophyll* ("middle region of leaf"). Of course it is these cells that contain the chloroplasts and are the working cells that the epidermis protects against the drying effect of air, and to which the stomata permit access of air. In horizontal leaves, the cells of the mesophyll usually are arranged differently in the upper and lower regions of the leaf. Those in contact with the upper epidermis are elongated at right angles to the surface of the leaf and stand in close contact, being the *palisade cells* (Fig. 157). The mesophyll cells beneath the palisade layer are irregular in form, and so loosely arranged as to leave air-spaces between the cells, the whole region forming the *spongy tissue* (Fig. 157). The air-spaces communicate with one another, forming a labyrinth of air-passages throughout the spongy mesophyll. It is into this system of air-passages that the stomata open (Fig. 157), so that all of the green cells are put in contact with the air. The picture of a leaf as a food-manufacturing machine, therefore, is that of an internal and moist atmosphere bathing the working cells and com-

municating with the external atmosphere through the stomata, which are able to regulate the freedom of this communication. Through this mechanism, the carbon dioxide of the external atmosphere diffuses into the internal atmosphere of the leaf and passes into the working cells, while the oxygen that passes from the cells into the internal atmosphere diffuses into the external atmosphere.

(3) *Veins.* — In the cross-section of the leaf there appear sections of the veins of various sizes, embedded in the mesophyll at varying intervals (Fig. 157). It has been stated that the veins bring to the mesophyll cells water that has come from the soil. It will be seen that the water-conducting part (xylem) of these vascular strands is towards the upper surface of the leaf, the natural position when it is remembered that the strand arises from the stem cylinder, where the xylem is on the inside, and turns outward into the horizontal leaf.

121. **Photosynthesis.** — The manufacture of carbohydrate food by green plants was outlined in Chapter III (p. 31) in connection with Algæ, so that it need not be repeated here. However, it should be remembered that the process described there is not only carried on by the leaf, but that the leaf is a particularly efficient machine for photosynthesis in plants exposed freely to the air. Water is carried in from the soil, carbon dioxide diffuses from the external atmosphere to the internal atmosphere through the stomata, the chloroplasts in the mesophyll cells lay hold of these materials with energy obtained from light and manufacture a carbohydrate, the oxygen waste diffuses from the internal atmosphere to the external atmosphere, and the whole living machine is kept from drying out by the epidermis with its layer of cuticle.

122. **Transpiration.** — Although water is being evaporated constantly from the surface of a living plant exposed to the air, foliage leaves are especially exposed to this evaporation

(*transpiration*), so that the loss by the leaves represents the largest amount of loss in an ordinary plant. It has been stated that the epidermis with its cuticle checks transpiration, but it does not prevent it entirely. The greatest amount of transpiration, however, is by way of the stomata, for the water vapor of the internal atmosphere, obtained from the cells, is diffusing continually into the external atmosphere. If the stomata are closed by the guard-cells and the internal atmosphere becomes saturated with water vapor, the loss of water from the working cells is very little or none at all. It is evident that the larger the air-spaces in the leaf, that is, the looser the leaf is in texture, the greater is the amount of internal atmosphere, and the more rapid is transpiration. Hence the amount of transpiration from a leaf depends more upon its structure than upon the extent of its exposed surface.

FIG. 160. — Transpiration experiment: a potted geranium sealed with a rubber cloth and covered with a bell jar; the mist and droplets of water on the glass more or less obscure the plant.

A simple experiment should be performed to demonstrate the fact of transpiration by placing a glass vessel (bell jar) over a small active plant, care being taken to shut off the

evaporation from the pot and soil by a rubber cloth (Fig. 160) or some other device. Moisture will be seen to collect on the glass and even to trickle down the sides. Some measurements of the loss of water by transpiration are as follows: a single stalk of corn lost four gallons of water in 173 days (the duration of its life); a single hemp plant lost nearly eight gallons in 140 days; a sunflower, whose leaf surface was approximately nine square yards, gave off nearly one quart of water in a single day. If such measurements be applied in a general way to the enormous area of leaf exposure in a forest, or to any great mass of vegetation, some vague idea may be obtained as to the enormous volume of water vapor that is being given off by plants.

Fig. 161. — A broad-leaved plant, showing the general horizontal plane of the leaf-blades.

Transpiration has been regarded usually as a menace to the plant, without any corresponding advantage. It was known that water must be supplied freely to the working cells to keep them in working condition, as well as to supply to green cells the water used in photosynthesis, and it was realized that loss of water by evaporation is inevitable. It has been demonstrated recently that transpiration is not so much a danger to the plant that must

be guarded against, as a means by which the working cells are kept at a working temperature. It is found that the heat from the sunlight would raise the temperature of a leaf dangerously if it were not tempered by the cooling effect of transpiration. Experiments show that if transpiration is stopped, leaves perish quickly. Transpiration, therefore, is a protection of very great importance; while

FIG. 162. — Leaves of geranium shifting position according to the direction of the light: *A*, the plant exposed to vertical rays of light; *B*, the same plant exposed to oblique rays of light.

the danger of transpiration is simply that the supply of water may not be equal to the necessary and beneficial loss.

Another very important advantage of transpiration is that the continual loss of water from the leaves results in a continual movement of water into the leaves. This mass movement of water in the plant towards the regions of loss (the regions of transpiration) is often called the *transpiration current*. This does not explain how the water moves

so much as the direction in which it moves. The importance of this mass movement of water not only consists in making good the loss through transpiration and thus insuring the continuation of transpiration, but also it carries to the working cells the soil materials especially necessary in the manufacture of proteins.

123. **Exposure to light.** — It is evident that leaves should be so adjusted as to receive as much light as possible without danger, for too intense light is dangerous. It is a problem of "just enough and not too much." The adjustment to

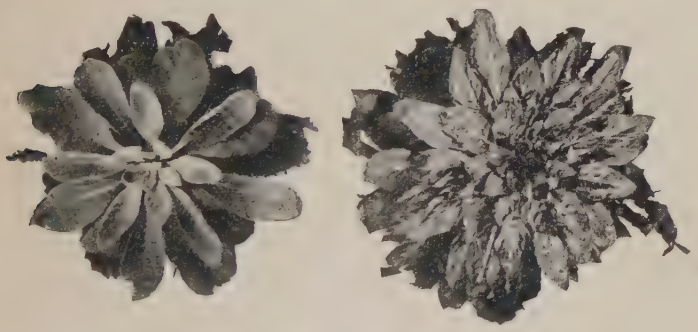


FIG. 163. — Rosette of mullein (*A*) and of evening primrose (*B*).

light, therefore, is a delicate one, for the exact position any particular leaf holds in relation to light depends upon many circumstances, and cannot be covered by a general rule, except that it should get all the light it can without danger.

The ordinary plane of a leaf is approximately horizontal (Fig. 161), a position which enables it to receive the direct and most intense rays of light upon its upper surface. Certainly in this position more rays strike the leaf than if its plane were oblique or vertical, the latter position often being spoken of as an "edgewise" position. Most leaves when fully grown are in a fixed position that has been determined by the conditions that prevailed during their development.

But some leaves are so constructed that they can shift their position as the direction of the light changes, or the stem bearing the leaves may shift its position so that a better relation to light is secured (Fig. 162). The leaves of window plants are often seen to adjust themselves so as to face the light, and by turning such a plant around so as to bring its other side towards the light, the leaves will become adjusted gradually to the new condition and face the light again.

It is evident that the leaves of a plant are in danger of shading one another, and while shading cannot be avoided, it can be diminished in various ways. The spacing apart of the leaves by the elongation of the internodes (§ 130, p. 224) is the most general method of avoiding extreme shading. The spiral arrangement of leaves on the stem, which prevents two successive leaves from standing in the same plane, is also a very general method of diminishing shading (Fig. 161). In many herbs whose leaves are rather large and close together, the petioles of the lower leaves are usually longer than those above, and thus their blades are thrust beyond the shadow of the upper leaves. The same result is obtained when the lowest leaves of a plant are the largest, and the upper leaves gradually diminish in size.

Fig. 164. — Rosette of shepherd's purse.

Some plants are in such a position that for protection (to be explained later) the leaves are produced in a cluster at the base of the stem. This is called the *rosette-habit*, and the rosette of leaves frequently lies flat upon the ground or upon

FIG. 165. — The leaf-mosaic of a *Begonia*.

the rocks (Figs. 163 and 164). This close overlapping of leaves is a very poor adjustment to light at best, but there is evident an adjustment to secure the most light possible under the circumstances. The lowest leaves of the rosette are the longest, and the upper ones become gradually shorter, so that each leaf has at least a part of its surface, and usually the broadest part, exposed to light.

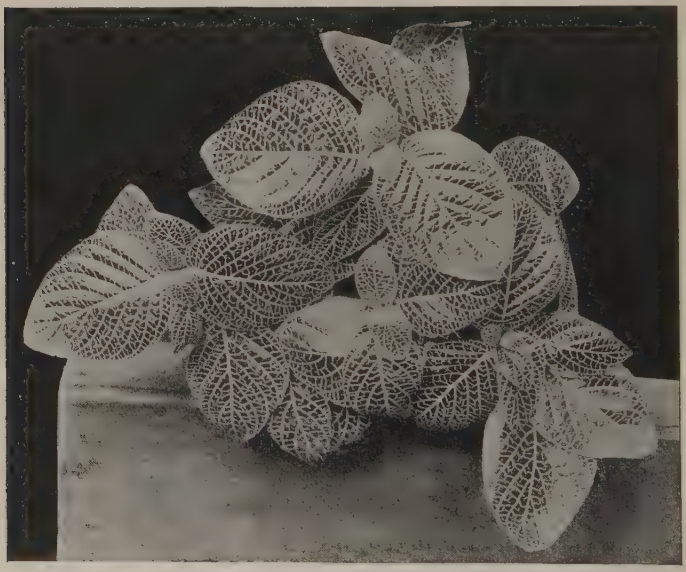


FIG. 166. — The leaf-mosaic of a *Fittonia;* observe also the beautifully distinct veining.

All of these adjustments to light may be brought together under the conception of a *leaf-mosaic*, by which is meant the arrangement of leaf-blades with reference to one another so that the greatest amount of leaf surface may be exposed to direct illumination. A general mosaic arrangement of leaves may be observed in connection with almost every broad-leaved plant (Figs. 165 and 166); and even when the leaves

FIG. 167.—The leaf-mosaic of the Japan ivy, often called Boston ivy.

are separated along an erect stem, a view from above, in which all the leaves are referred to a single plane, shows the mosaic arrangement. In many trees in dense forests, notably in the tropics, the leaves appear chiefly and sometimes exclusively at the extremities of the branches, often producing a magnificent dome-like mosaic.

Fig. 168. — Section through a small portion of a carnation leaf, showing epidermis overlaid by a very heavy cuticle; a single stoma in the epidermis, opening without into a tubular passageway through the cuticle, and within into an air-chamber; below are the mesophyll cells containing chloroplasts.

In the case of stems exposed to direct light only on one side, as the horizontal branches of trees, stems prostrate on the ground, and stems against a support (as climbers and twiners), the leaf-blades are brought to the light side so far as possible. Looking up into a tree in full foliage, one will notice that the horizontal branches are comparatively bare beneath, the leaf-blades being displayed on the upper side as a mosaic. The most literal and complete mosaic is shown by certain ivies, whose leaf-blades are so adjusted to light that the surface of a wall is covered completely by leaf-blades fitted together in a living mosaic (Fig. 167). The ivy mosaic is striking chiefly because the leaf-blades are all displayed in approximately a single plane.

124. **Protective structures.** — The protection most widely needed by land plants is against excessive loss of water, and since the leaves are the prominent transpiring organs, the chief methods of protection concern them. Drought is usually accompanied by intense light, which is also dangerous to the chloroplasts. The problem of drought is presented to plants in three aspects: (1) the possible drought,

which may occur at any time or not at all; (2) the periodic drought, which is a regular season of the year; (3) the perpetual drought, which characterizes arid regions, such as the states on the Mexican border. It is evident that the ordinary crop-producing regions of this country come under the first head, and that a possible drought is the hardest kind to provide against. When there is a regular period of drought, the life-histories of plants become adjusted to it,

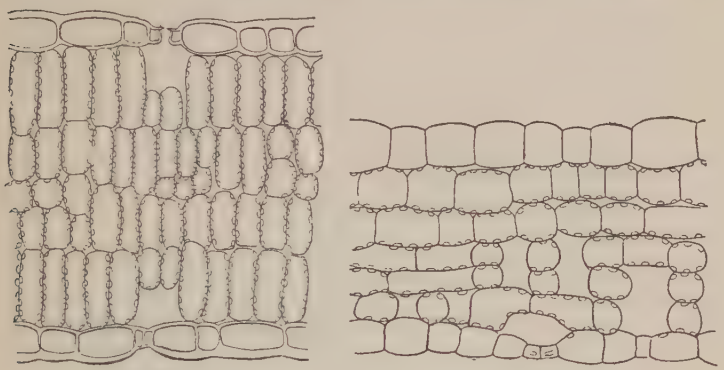


FIG. 169. — Sections through leaves of the same plant, showing the effect of exposure to light upon the structure of the mesophyll: *A*, leaf exposed to intense sunlight; *B*, leaf grown in the shade. — After STAHL.

just as to a winter period; when there is perpetual drought, only those plants equipped for it succeed in living, or it is controlled by irrigation; but when drought comes at irregular intervals, it is usually a question of the endurance of poorly equipped plants. The subject of protection is too large and complex to be presented with any completeness, and therefore a few illustrations of protection that seem to be definite must suffice.

In the description of the structure of leaves attention was called to the fact that the epidermis with its layer of cuticle is an ever-present check against transpiration. Of course

the epidermis is always present, but the amount of cuticle (Fig. 158) may vary widely. It is in plants of dry regions that the cuticle may become very thick, layer after layer being added to it by the epidermal walls beneath. In some cases the cuticle becomes so thick that the passageways through it to the stomata resemble short tubes (Fig. 168), the stomata being said to be "sunken."

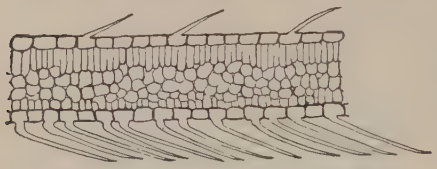


FIG. 170. — Section through the leaf of bush clover, showing the usual leaf structure, and also the numerous simple hairs produced by the lower epidermis; observe that the hairs bend sharply and lie along the surface of the leaf.

The layer of palisade cells (Fig. 157), which is developed

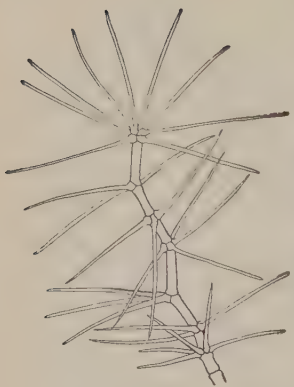


FIG. 171. — Branching hair of mullein.

FIG. 172. — Scale from the leaf of *Shepardia;* such scales overlap and form a complete covering.

in leaves whose two surfaces are unequally illuminated, must tend to diminish transpiration by exposing only the

ends of elongated cells which stand so close together that there is no drying air between them. It seems probable, however, that palisade development has more to do with the intensity of light than with drought. Figure 169 shows in a striking way the effect of different light intensities upon the structure of the mesophyll of leaves of the same plant. It has been observed that the chloroplasts are able to assume various positions in cells, in very intense light moving to the more shaded depths of palisade cells, and in less intense light moving to the more external regions of the cells.

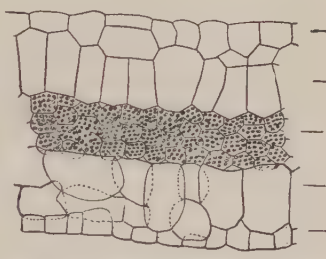


FIG. 173. — Section through a leaf of *Begonia*, showing epidermal layers (*e*), water storage tissue (*w*), and the central cells containing chloroplasts (*c*).

Hairs and scales are very common outgrowths from the epidermal cells of leaves and stems (Figs. 170–172), and it is natural to associate them with the idea of protection of some kind. But they are not related to drought or to intense light definitely enough to make it clear that they are a protection against these dangers. It has been suggested that hairy plants are characteristic of dry regions, and also that a covering of hairs is an effective sun screen in regions of intense light, but there also are many hairy plants in moist and well-shaded forests.

Small leaves are also characteristic of dry regions, and it is easy to see that a small leaf exposes a small surface to the drying air and the intense light, but the total leaf exposure on a plant may not be reduced. That the reduction in size holds a direct relation to the dry conditions is evident from the fact that the same plant often produces small leaves in dry conditions and larger ones in moist conditions, but this is more evidently a response to conditions for growth than an effort to check transpiration.

The most notable protective structure in plants of dry regions, aside from the ever-present epidermis and cuticle, is the *water storage tissue*. This is not a protection against loss of water, but the same end is accomplished by storing water. Usually the water reservoir is a definite tissue, often being distinguished from the green working cells in leaves by being a group of colorless cells (Fig. 173.) In

FIG. 174. — *Agave* (maguey), showing rosette of fleshy leaves. — Photograph by LAND near San Luis Potosi, Mexico.

regions of perpetual drought, the leaves may become thick and fleshy on account of extensive water storage tissue, as in the agave (Fig. 174). In the cactus the leaves have been abandoned as foliage organs, and the peculiar stems have become great reservoirs of water. The globular body, so common a cactus form (Fig. 175), may be taken to represent the form of body by which the least amount of surface may be exposed and the greatest amount of water storage secured. In the case of these fleshy leaves and bodies, it has long been

noticed that they not only contain water, but also have great power of retaining it.

The need of protection against drought and intense light is probably obvious to every one, but that leaves need to be protected against rain is not often considered. Rain falling upon plants is felt to be a blessing rather than a menace, and so it is if the leaves are protected properly. If the water

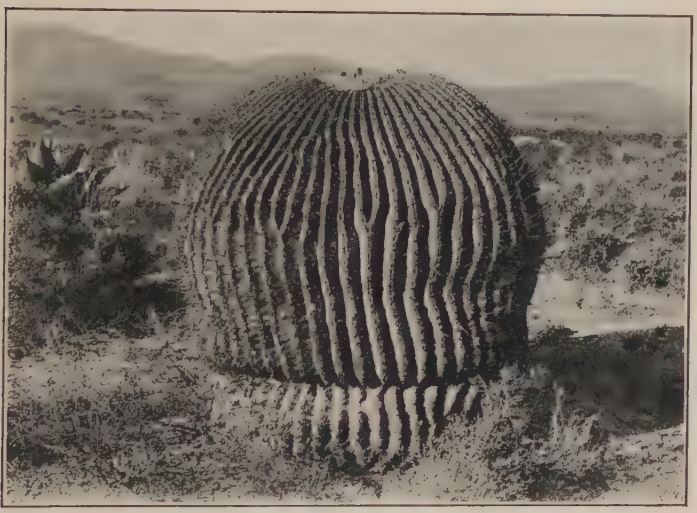


Fig. 175. — A globular cactus. — Photograph by Land near Tehuacan, Mexico; note the coin (a dollar) fastened to the base, to indicate the size of the plant.

soaks into the leaves and fills up the air-spaces, replacing the internal atmosphere, the communication of the working cells with the external atmosphere is cut off. This would be as dangerous to the leaf as if water should replace the internal atmosphere in a man's lungs; in other words, the leaf would be drowned. The impression that leaves take in water when it rains is doubtless due to the common observation that when wilted leaves are sprinkled they "revive," the inference being that the sprinkled water has passed into the leaves. The

leaves have wilted because they have been losing water at a more rapid rate than it has been supplied to them, and the effect of the sprinkling is to check this loss by developing a moist atmosphere about the leaves, so that it shall not exceed the supply that is coming from the roots. In other words, sprinkling provides a dam against water loss, and allows water to accumulate again in the leaves; so that the water that " revives " wilted leaves is not that which is sprinkled, but that which is coming all the time from the roots and is now allowed to accumulate a little.

FIG. 176. — A leaf of a rainy tropical forest, with a drainage system of sunken veins and a spout-like point. — After SCHIMPER.

Some of the structures that prevent the rain from soaking in are a smooth epidermis, a cuticle, a waxy deposit, felt-like coverings of hairs, overlapping scales (like shingles on a roof), etc. In the rainy tropics, where this danger is extreme, it is very common for the sunken veins and ribs of the leaves to form a sort of drainage system for carrying off water, the main channel lying along the midrib, which terminates in a long spout-like point (Fig. 176).

125. **Protective positions.** — Leaves are protected against drying air and intense light not only by their structures, but often also by their positions, and such plants are unusually well-equipped to endure exposure.

Perhaps the most common method of protection used by small plants growing in exposed situations, as bare rocks and sandy soil, is the rosette-habit (§ 123, p. 200) (Figs. 163 and 164). The clustered leaves, flat upon the ground or nearly so, and more or less overlapping, form a very effective arrangement for resisting intense light or drought; but it must be remembered that it is not an effective arrangement of leaves for work, it is only an effective arrangement for protection, so that work may go on in unfavorable conditions.

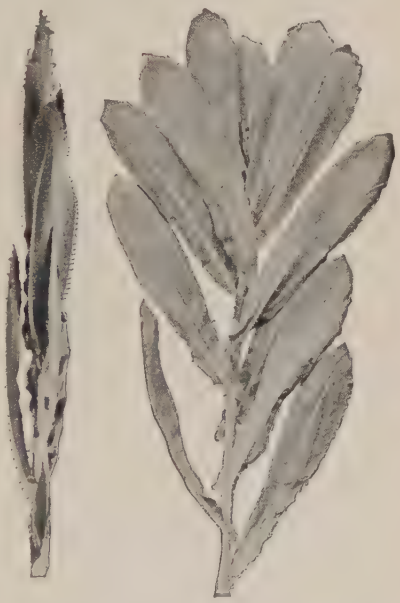


Fig. 177. — Prickly lettuce, showing the profile (edgewise) leaves from two points of view.

A position developed by the leaves of some plants in regions of intense light is the *profile* position, and such leaves are called *profile leaves*, a margin being directed upwards and the leaves, in this way, standing edgewise. This position results in turning away the faces of the leaves from the intense rays of midday and exposing them to the morning and evening rays of less intensity. In the dry regions of Australia the leaves of many of the forest trees and shrubs are profile leaves, giving to the foliage a very peculiar appearance. The best known illustration of a plant in this country with profile leaves is the "compass plant," a rosinweed of the prairie region. Its name was given because its edgewise leaves were observed to point in a general north and south direction,

serving the purpose of a compass. It was actually thought, for a time, that the direction of these leaves is controlled in some mysterious way by magnetic influence; but it is evident that the plane of a profile leaf, exposing its faces to the morning and evening sun, will lie in a general north and south direction. In other words, the leaves point north and south because the sun rises in the east and sets in the west. It is a significant fact that compass plants grown in the shade do not develop profile leaves. It must not be supposed that there is anything like accuracy in the north and south direction of a profile leaf.

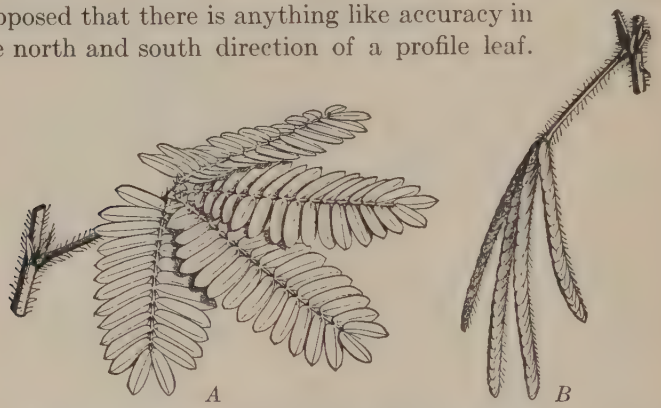


FIG. 178.— Leaf of sensitive plant in two conditions: *A*, fully expanded, with the four main branches and numerous leaflets well spread; *B*, after a shock of some kind, the leaflets having been thrown together forward and upward, the four branches having been moved toward each other, and the main petiole having dropped sharply downward. — After DUCHARTRE.

It may be the prevailing general direction of the profile leaves of the rosinweed referred to, but in the prickly lettuce (Fig. 177), a very common weed of waste grounds even in cities, and one of the most striking of the compass plants, the profile position is frequently assumed without any reference to the north or south direction of the apex.

Still more specialized are the *motile leaves*, which have the power of shifting their position according to the needs, directing their flat surfaces towards the light, or more or less

inclining them. Such leaves have been developed most extensively in the pea family, and the most conspicuous illus-

FIG. 179. — The day (*A*) and night (*B*) positions of the leaves of a clover-like plant. — After STRASBURGER.

trations are the " sensitive plants " of the drier regions. The name has been given because the leaves respond to various stimuli by changing position with remarkable rapidity. A slight touch, or even jarring, will call forth a response from the leaves, and the sudden application of heat gives striking results. The leaves of the best known sensitive plant (Fig. 178) are divided into very numerous small leaflets, which stand in pairs along the leaf branches. When a drought begins, some pairs of leaflets come together face to face, slightly reducing the surface exposure. If the drought continues, more leaflets come together, then still others, until finally all the leaflets may be in contact in pairs, and the leaves themselves may droop against the stem. In this way the exposed surface may be regulated according to the need, on

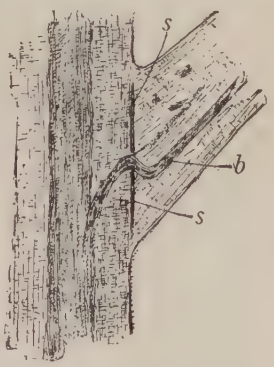


FIG. 180. — Diagrammatic section through a node of horse chestnut, showing the position of the cutting-off layer (*s*) and the vascular bundle (*b*) not cut through.

the same principle that a sailing vessel may regulate its sail-exposure according to the need. Motile leaves also shift their positions throughout the day in reference to light; and at night a very characteristic position is assumed, once called a "sleeping" position, but better called a night position. The contrast between the day and night positions of many leaves, even clover leaves (Fig. 179), is quite striking. These night positions may be induced experimentally by placing plants in darkness.

FIG. 181. — A pine twig, showing the needle-leaves, and a cluster of staminate cones. — Photograph by LAND.

126. **The fall of leaves.** — Many shrubs and trees of temperate regions lose their leaves every year, usually at the approach of winter, putting out new leaves in the following spring. This is called the *deciduous* habit, and such trees are called *deciduous trees*. While in some deciduous trees, as the oaks, there is no special preparation for "shedding" leaves, in most of them a special plate of cells is formed near the juncture of the leaf with the stem, known as the "cutting-off layer," which gradually separates the leaf from the stem, so that it falls by its own weight or is wrenched off by the wind (Fig. 180).

In connection with the deciduous habit there often appears the autumnal coloration of leaves, so striking a feature of temperate forests. The colors that appear are shades of yellow and red, either pure or variously intermixed. They

are the result of the waning activity of the leaf, the yellow mostly being the color of the dying chloroplasts, and the red coming from the presence of a new substance produced in the enfeebled cells. The popular belief that these colors are caused by frost is only partly true, for they often appear before there has been any frost; but they may be induced by any conditions that tend to diminish the activity of the leaf, and cold is one of the conspicuous conditions.

In contrast with the deciduous shrubs and trees are the so-called "evergreens," in which there is no regular annual fall of leaves. Such leaves endure for a varying length of time, but as there is no regular period for all of them, the shrub or tree always appears in foliage. In the temperate regions, the most conspicuous evergreens are the pines and their allies. A comparison between the needle-leaf of a pine (Fig. 181) and the leaf of an ordinary deciduous tree will show what the evergreen habit involves in temperate regions. The pine leaf must be protected so as to endure the winter, and this has involved reduction in surface and extremely thick protective layers about the mesophyll (Fig. 182). This has diminished the ability to work, but it has saved the tree the necessity of putting out a complete new crop of leaves for the next season. In other words, the cost of the winter protection of leaves is a loss of working power during the spring and summer. The deciduous leaf, on the other hand, is broad and thin, with great capacity for work; but this for-

FIG. 182. — Cross-section of a pine needle, showing epidermis with sunken stomata, groups of heavy-walled cells beneath epidermis, the mesophyll (the cells characterized by curious infolded walls) containing seven resin canals, and the central vascular region containing two bundles (xylem uppermost).

bids protection during the winter. It is merely a balancing between protection and work; the evergreens lay emphasis on protection, and the deciduous plants on work.

127. **Special forms of leaves.** — We have been considering leaves as foliage, but in many cases they are so modified that they either lose their character as machines for the manufacture of carbohydrate food, or add to it some other work. In so far as they remain green, they manufacture carbohydrates as do the foliage leaves, but a definite change in structure and behavior indicates that they are constructed for some other kind of work also. This subject is a very extensive one, so that only some of the conspicuous illustrations will be noted.

FIG. 183. — Pinnately compound leaf of garden pea, whose terminal portion has developed as tendrils. — After STRASBURGER.

In certain situations leaves are not free to develop to full size, and when this happens they may not develop chloroplasts, so that they do not even become green. Such leaves are called *scales*. They are often called "reduced" leaves, but they have not been reduced from a larger size; they have never developed to a larger size. The most conspicuous illustrations of scales are found among plants with subterranean stems and in connection with "scaly" buds. One of the features of a stem is to produce leaves, but underground stems cannot produce foliage leaves unless, as in ferns, the leaves reach the surface and develop in the light. When they do not reach the surface, the leaves appear as small scale-like bodies without green tissue. Often these scales seem to be

merely useless relics, but sometimes they are used for food storage, as in lily bulbs, onions, etc., which are mostly made up of fleshy scales. In the scaly buds, so common on shrubs and trees, the leaves are prevented from developing by being kept close together, so that they overlap. These overlapping bud scales are clearly useful as protective structures, and to this end they are generally firm and resistant, often coated with resin, and the inner ones frequently clothed with woolly hairs.

Leaves may sometimes develop as tendrils, either the whole leaf or some of its branches becoming tendrils, as in the sweet pea (Fig. 183). Tendrils are peculiarly sensitive to contact, and the resulting curvature grips the body touched, and a succession of tendrils thus enables a plant to "climb."

FIG. 184. — Leaves of barberry developing as thorns.

Leaves are sometimes developed as thorns, as may be observed in the barberry (Fig. 184), or sometimes only certain regions of the leaf become thorns, as in the common locust, acacia, etc.

The most singular use of leaves, however, is for catching

insects. Plants with such leaves are often called "carnivorous plants" or "insectivorous plants," since the captured insects are used for food. This is merely one way of getting protein food without manufacturing it, and at the same time such leaves are usually green and manufacture their carbohydrate food. Three conspicuous illustrations of insect-catching leaves will be given.

The "pitcher-plants" are so named because the leaves form tubes or urns of various forms, which contain water, and to these pitchers insects are attracted and then drowned. The common pitcher-

FIG. 185. — Leaves of the common northern pitcher-plant, one of them cut across to show cavity and wing. — After GRAY.

FIG. 186. — Leaf of a southern pitcher-plant, showing the funnel form and winged pitcher, and the overarching hood with translucent spots. — After KERNER.

plant of the northern states (a *Sarracenia*) is a well-known bog plant (Fig. 185), but it is not so elaborately constructed for capturing insects as is a common southern *Sarracenia* (Fig. 186). In this plant the leaves are slender, hollow cones, and rise in a tuft from the swampy ground. The mouth of this conical urn is overarched and shaded by a hood, in which are

Fig. 187. — Leaves of the Californian pitcher-plant, showing the twisted and winged pitcher, the overarching hood with translucent spots, and the fish-tail appendage to the hood. — After Kerner.

Fig. 188. — Leaf of *Nepenthes*, showing the blade-like base, the tendril portion, and the terminal pitcher with its lid. — After Gray.

translucent spots, like numerous small windows. Around the mouth of the urn are glands which secrete a sweet liquid (*nectar*). Inside, just below the rim of the urn, is a glazed zone, so smooth that insects cannot walk upon

it. Below the glazed zone is another one thickly set with stiff, downward-pointing hairs; and below this is the liquid in the bottom of the urn. If a fly, attracted to the nectar at the rim of the urn, attempts to descend within the urn, it slips on the glazed zone and falls into the water; and if it attempts to escape by crawling, the downward-pointing hairs prevent. If it seeks to fly from the rim, it naturally flies towards the translucent spots in the hood, since the direction of entrance is in the shadow; and pounding against the hood, the fly usually falls into the tube. The pitchers usually contain the decaying bodies of numerous drowned insects. A much larger Californian pitcher-plant is *Darlingtonia* (Fig. 187), whose leaves are one and a half to three feet high, the hood bearing a gaudily colored "fish-tail" appendage, the whole structure being a more elaborate insect trap than are the leaves of *Sarracenia*. In these traps not only are the remains of flies found, but bees, hornets, butterflies, beetles, grasshoppers, and even snails have been reported. The species of *Nepenthes*, from the oriental tropics, very common in conservatories, develop most remarkable leaves, the lowest part being an ordinary blade, beyond which is a well-developed tendril, at the end of which there arises an elaborate pitcher with a lid (Fig. 188).

FIG. 189. — Sundews. — After KERNER.

There is the same sweetish secretion at the rim of the pitcher, and the same accumulation of water within as in the ordinary pitcher-plants.

The "sundews" are forms of *Drosera*, and grow in swampy regions, the leaves forming small rosettes upon the ground (Fig. 189). In one form the blade is round, and the margin is beset by prominent bristle-like hairs, each with a globular

FIG. 190. — Two leaves of a sundew: *A*, glandular hairs fully extended; *B*, half the hairs bending inward, in position assumed when an insect has been captured. — After KERNER.

gland at its tip (Fig. 190). Shorter gland-bearing hairs are scattered also over the inner surface of the blade. All these glands excrete a clear, sticky fluid, which clings to them like dewdrops, and which, not being dissipated by sunlight, has suggested the name sundew. If a small insect becomes entangled in one of the sticky drops, the hair begins to curve inward, and presently presses its victim down upon the surface of the blade. In the case of a larger insect, several of the marginal hairs may join together in holding it, or the whole blade may become more or less rolled inward.

The "Venus fly-trap" (*Dionæa*) is one of the most famous and remarkable of insect-trapping plants, being found only in certain sandy swamps near Wilmington, N. C. The leaf-blade is constructed so as to work like a steel trap, the two halves snapping together and the marginal bristles interlocking like the teeth of a trap (Fig. 191). A few sensitive hairs, like feelers, are developed on the leaf surface; and when one of these is touched by a small flying or hovering insect, the trap snaps shut and the insect is caught. Only after digestion, which is a slow process, does the trap open again.

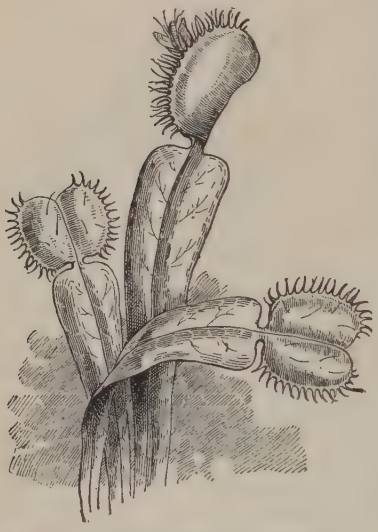


FIG. 191. — Three leaves of *Dionæa:* two with the traps open, one with trap shut on an insect. — After KERNER.

128. **Summary.** — Leaves are essentially expansions of green tissue organized for the work of photosynthesis, and therefore exposed to light and air. The variations in the forms and superficial structure of leaves are extremely numerous, but the essential structure comprises an epidermis which protects the working cells against excessive loss of water, a mesophyll region which is made up of the green working cells, and veins which distribute water among the working cells. The expanded form of the leaf is maintained by the comparatively rigid framework of veins, and by turgor of the mesophyll cells.

The necessary relations of leaves to light involve adj ments to prevent an excessive shading of leaves by one other. The most general statement of the situation is t

the leaves of a plant are so adjusted to one another that they form a mosaic.

The necessary exposure of leaves to the light involves the corresponding danger of excessive transpiration. The protective structures against the danger of transpiration are chiefly the epidermis with its cuticle, the palisade layer, and water-storage tissue. The plants further equipped for protection by the position of their leaves are those which have the rosette habit, or profile leaves, or motile leaves.

While foliage leaves may be regarded as representing the usual leaf, they may be replaced by structures that do not have the appearance, nor, in many cases, the function of foliage leaves. Such replacing structures are called "modified" leaves chiefly because they appear in the position usually occupied by leaves.

CHAPTER XII

STEMS

129. **General character.** — A stem is characterized by bearing leaves, and this involves two problems: (1) the display of leaves, and (2) the conduction of water. Stems are not always rigidly erect, for they may be prostrate or climbing; neither are they always aërial, for many stems are subterranean. Often stems are unbranched (*simple*), in which case the leaf display is relatively small; often they are branched, which simply means an increased capacity for leaf display, which reaches its maximum in certain types of trees.

What is called the *habit*, that is, the general appearance of a plant, is determined by the character of the stem, the leaves being a constant feature in every case. For example, trees are recognized in winter by their stem habit as easily as when they are in foliage.

130. **Leaf display.** — There are some general facts about the display of leaves by aërial stems that should be recognized. The stem (or branch) of a seed-plant does not produce leaves indiscriminately throughout its whole length, but at certain definite regions called the *nodes*, the regions between the nodes being called *internodes*. This means that the stem is differentiated into two regions, the nodes that bear leaves and the internodes that do not, and these two regions differ also in structure. The significance of this differentiation is that while the nodes are constructed to produce leaves, the internodes are constructed to elongate, so that the leaves are separated. Plants vary in the amount of the separation of

their leaves, and this is a measure of the power of the internodes to elongate. It is evident that leaves separated by the internodes to such an extent that they do not shade one another are in the most favorable condition for work.

FIG. 192. — A scarlet runner bean, showing leaf-bearing nodes, internodes, and axillary branches.

In such a stem, the leaves begin to form before the internodes begin to elongate, so that the young leaves are packed together in the structure called a *bud;* that is, a leaf-bud as distinct from a flower-bud. When the internodes begin to elongate, the bud is said to "open," and this opening goes on until all appearance of a bud is lost. While the bud is opening the young leaves become more free and continue their development, so that when the internodes have reached their full length, the young stem (or branch) bears developed leaves, and the plant is said to be "in foliage." The picture of leaves developing on a stem, therefore, is not that of an elongating stem putting out leaves, but that of an elongating stem separating growing leaves that have been "put out" by the nodes.

FIG. 193. — The so-called "wedding smilax" showing branches that resemble leaves arising from the axils of minute scales that are the real leaves.

The nodes not only produce leaves, but if the stem branches, the nodes produce the branches also. It has long been observed that a branch arises at a node immediately above a leaf, that is, in the upper angle between leaf and stem, which is called the *axil* of the leaf (Fig. 192). This usual relation of branches to leaves is merely a relation of position, which is determined by the fact that nodes are constructed to produce

FIG. 194. — The arrangement of leaves: *A*, spiral or alternate leaves; *B*, opposite (cyclic) leaves; *C*, whorled (cyclic) leaves. — After GRAY

"lateral members," which in this
branches. Why branches do not usu
leaves or below them is a matter of det
cern us here. However, it is so usual for a branch to arise from the axil of a leaf that this relative position is often used in determining the nature of a structure. For example, a structure that has a branch in its axil, even if it is a tendril or a thorn, is regarded as a leaf; and conversely, a structure that arises from the axil of a leaf, even if it is a thorn or a

tendril or even a good leaf in appearance (Fig. 193), is regarded as a branch. Since the significance of a structure is determined by what it can do, it makes little difference what its

FIG. 195. — An Austrian pine.

origin really is. A tendril does the work of a tendril, whether it is a leaf or a branch that has been "modified."

Plants differ as to the number of leaves produced by each node. In very many cases only a single leaf is produced by

a node, and then the leaf from the next node above does not arise directly over the leaf below (Fig. 194, *A*). If an imaginary line be drawn connecting the points on the nodes

Fig. 196. — An elm in foliage.

at which successive leaves appear, it will form a spiral winding about the stem. Leaves with this arrangement, therefore, are said to be *spiral* (also commonly called *alternate*).

It is evident that this spiral succession of leaves results in reducing to a minimum the shading of the leaves by one another. In other plants two or more leaves appear at each

Fig. 197. — An oak in winter condition.

node (Fig. 194, *B* and *C*), and such leaves are said to be *cyclic* (very commonly, two leaves at a node are said to be *opposite*, and three or more leaves at a node are said to be *whorled* or

verticillate). In the case of cyclic leaves, the cycle of one node does not stand directly over the cycle of the node just below it, but over the spaces between the leaves below. All these terms, however, need not confuse, for the fundamental fact is that leaves appear at the nodes in spiral succession, the so-called " spiral " or " alternate " leaves referring to a single spiral of leaf succession ascending the stem from node to node, and the so-called " cyclic," " opposite," " whorled," or " verticillate " leaves referring to two or more spirals of leaf succession ascending the stem from node to node.

Fig. 198. — Prostrate stem of *Potentilla*.

131. **Stem-position**. — It is obvious that the ideal position of a stem for leaf display is a free erect position, for leaves can be displayed freely on all sides. Of course to maintain a free erect position is not a simple mechanical problem, and in such stems this problem must be added to the universal one of water-conduction. That erect aerial stems must be constructed to maintain their position becomes evident when they are contrasted with erect submerged stems. In small lakes and slow-moving streams such submerged stems are commonly seen, as the pickerel-weed and numerous other forms. In the water their stems are erect, but when taken out of water they collapse, having been maintained in position by the buoyant power of water.

The most impressive stem in relation to leaf display, both in character and amount, and also in its construction for maintaining a rigidly erect position, is the tree. But trees differ in the completeness of provision for leaf display. In some trees, as the pines and their allies (Fig. 195), the main stem continues as a central shaft to the top, the branches spreading horizontally from it, resulting in a general conical outline. In other trees, as the elm (Fig. 196) and the oak (Fig. 197), the main stem soon divides into branches, and there is a great spreading top or "crown," which represents the most complete provision for a maximum amount of leaf surface well displayed.

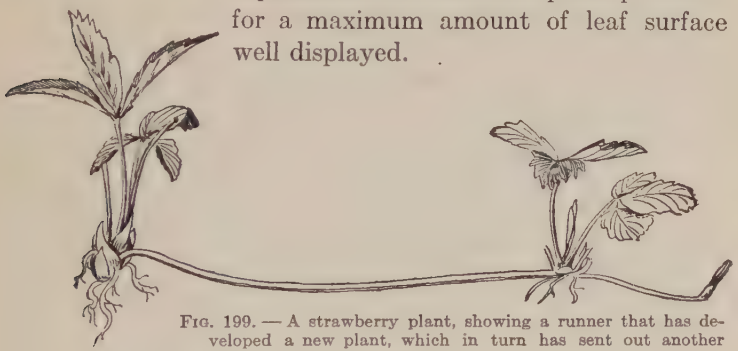


FIG. 199. — A strawberry plant, showing a runner that has developed a new plant, which in turn has sent out another runner. — After SEUBERT.

There are certain conditions, however, in which the free erect position of aerial stems is not maintained. In some plants the stem or certain of its branches lie prostrate on the ground or nearly so, sometimes spreading in all directions and becoming interwoven into a mat or carpet (Fig. 198). Such plants grow in general on sterile and exposed soil, and there may be an important relation between this fact and their habit. A prostrate stem is in a distinctly disadvantageous position for leaf display, for instead of being free to spread its leaves out in all directions, the free space for leaves is diminished at least one-half. Although freedom for leaf-display is restricted, prostrate stems are in a very favorable

position for vegetative propagation, and many prostrate plants respond to the favoring conditions. As the prostrate stem advances over the ground, roots develop from the nodes and enter the soil, and a new plant is started, which becomes independent by the death of the older parts or by separation from them. In this way a plant may spread over the ground, multiplying itself indefinitely. A very familiar illustration is furnished by the strawberry plant, which sends out peculiar leafless branches called "runners," which "strike root" at the tip and start new plants which become independent by the death of the runners (Fig. 199).

Prostrate stems illustrate the fact that nodes can produce not only leaves and branches, but also roots, if placed in suitable conditions. Advantage is taken of this fact in the common process of "layering," in which such stems as those of blackberries and raspberries are bent down to the ground and covered with soil, when the covered nodes strike root and new plants are started. When any plants are propagated by pieces of stem, known as "slips" or "cuttings," as in grape culture, it is because nodes can develop roots and thus make possible independent plants. The nodes of some plants put out roots when not covered by soil or even in contact with soil. For example, the erect stem of corn sends out roots freely from the nodes near the ground, and the poison-ivy and trumpet-creeper cling to supports by tendril-like roots produced by the nodes.

All that has been said emphasizes the importance of nodes, which can produce leaves, stems, and roots; and therefore a single node from an old plant may make a new plant possible. This is further emphasized in the method of propagating potatoes, which are thickened subterranean stems called *tubers* (Fig. 217). It is well known that when a tuber is cut in pieces for planting, each piece must contain one or more "eyes." An "eye" is a branch bud in the axil of a minute scale-leaf. There is no special virtue in the eye

except that it locates a node, and it is the node that starts the stem and root for a new plant.

A third stem-position may be called the climbing position, by which a better exposure of leaves to light may be secured than in a prostrate position, but no more free space for leaf display, since the support cuts off the space for display on one side. In fact, a prostrate stem on exposed soil is about the equivalent

Fig. 200. — A bean turning about a support.

Fig. 201. — Branch of star-cucumber, with its tendrils in various conditions.

of a climbing stem in a dense forest, where climbing plants become especially conspicuous, so far as leaf display is concerned.

132. **Responses of climbing plants.** — Climbing stems are often spoken of as "twiners" and "climbers"; in the former case the stem twining about a support, as the morning-glory, bean (Fig. 200), hop-vine, etc.; in the latter case

tendrils are formed that either hook about a support, as the grape-vine and star-cucumber (Fig. 201), or produce disk-like suckers at their tips that act as holdfasts (Fig. 202), as the woodbine or Virginia creeper (Fig. 203). The twining stem and the tendril exhibit responses to stimuli that should be observed.

If a young morning-glory or twining bean be watched (Fig. 200), it will be discovered that the elongating stem is unable to stand upright, and that, as it bends over, the inclined part begins to swing through a horizontal curve, which may bring the stem in contact with a suitable support. If this happens, the stem, continuing to swing in a curve and growing in length at the same time, winds itself about the support. This movement of the portion of the stem which is in a horizontal position is thought to be brought about by a peculiar response of the plant to gravity.

Fig. 202. — Woodbine clinging to a wall by means of tendril suckers.

Tendrils are illustrations of plant structures that are unusually sensitive to contact. When the tip of a tendril in moving about touches a suitable support, the side touched becomes concave and the tendril hooks or coils about the support. This is only the first response of the tendril to contact, for presently the rest of it begins to curve, a movement which results in spiral coils, since the tendril is fastened at both ends. This curving and twisting of the tendril between

its fastened extremities naturally results in two spiral coils running in opposite directions. In this way the stem is fastened to its support by numerous spiral springs. All of these movements and their results may be observed by cultivating a plant such as the star-cucumber, which grows rapidly and has conspicuous and very sensitive tendrils (Fig. 201). In the case of the ordinary climbing

Fig. 203. — Woodbine in a deciduous forest.

woodbine and certain species of ivy, which cling to walls or tree trunks, the tip of the tendril when it comes in contact with a support is stimulated into developing the disk-like sucker which acts as a holdfast (Fig. 202).

133. **Stem-structure.** — There are two general types of stem-structure exhibited by Seed-plants, one belonging to the Gymnosperms and Dicotyledons, and the other to the Monocotyledons. Since the latter is only a modification of the former, the stem of a Dicotyledon will be used as an illustration.

If an active twig of an ordinary woody plant be cut across, it will be seen that it is made up of three general regions (Fig. 204): (1) a zone of spongy tissue, usually green, the *cortex*, and covered by the

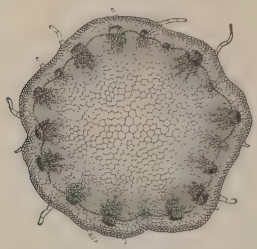


FIG. 205. — Cross-section of the stem of a buttercup (an herb), showing the well-separated bundles that form the vascular cylinder, leaving broad pith rays; observe also the very large pith, the cortex, the hairs arising from the epidermis, and especially the cambium cells between the xylem and phloem and continuing across the pith rays.

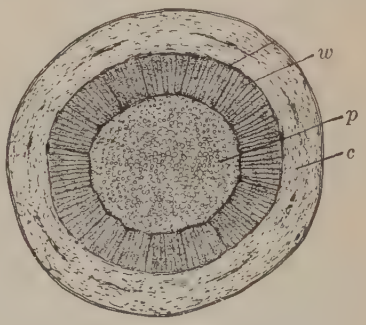


FIG. 204. — Cross-section of a branch of box-elder one year old: *c*, cortex; *w*, vascular cylinder; *p*, pith.

epidermis; (2) a relatively broad zone of firm wood, the *vascular cylinder;* and (3) in the center the *pith*. The special feature of this arrangement is that the wood oc-

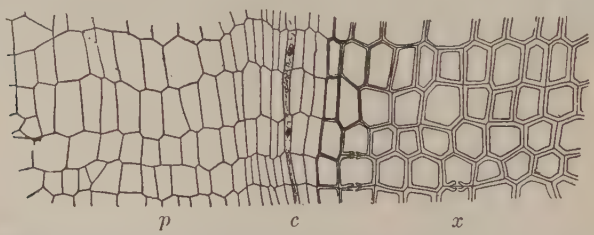


FIG. 206. — Cross-section of vascular bundle from pine stem, showing xylem (*x*), cambium (*c*), and phloem (*p*); on each side of the single row of cambium cells there are young xylem and phloem cells that pass gradually into the mature condition.

curs as a hollow cylinder, inclosing the pith and surrounded by the cortex. In the older parts of stems the pith often disappears, leaving a hollow stem. The cortex

is the active working region of the stem; since it is green it is able to manufacture carbohydrates as do the leaves, and it is also concerned in other work connected with nutrition. The vascular cylinder, on the other hand, is the great conducting region, as well as one that gives rigidity to the stem.

If the vascular cylinder be examined closely, it will be seen that it is broken up into segments by plates of cells that traverse it from the pith to the cortex (Fig. 204), these radiating plates of cells being the *pith rays*. The cylinder is thus made up of a number of segments which are called *vascular bundles*. The peculiarity of the structure of the stem in Gymnosperms and Dicotyledons, therefore, can be described as the arrangement of the vascular bundles so as to form a hollow cylinder. In woody stems the bundles are very close together in the cylinder, forming a compact cylinder with narrow pith rays (Fig. 204); but in the stems of herbs the bundles are well separated, leaving broad pith rays (Fig. 205).

If the cross-section of an individual vascular bundle be examined under the microscope, two regions will be recognized (Fig. 206), the inner one, toward the pith, being the *wood* (*xylem*), and the outer one being the *bast* (*phloem*). A vascular bundle, therefore, is made up of xylem and phloem, which differ from one another in the work of conduction, the xylem chiefly conducting the water that enters the plants by the roots and is passing to the leaves, and the phloem chiefly conducting prepared food.

The cells of the xylem that conduct water are called *tracheary vessels*. They are more or less elongated, and have very thick walls, upon which there appear markings of various kinds (Fig. 207). These markings may be seen in a longitudinal section through the wood. Some of the vessels are marked by a spiral band that extends from end to end, and are called *spiral vessels* (Fig. 207, *A*); others

show a series of thickened rings, and are called *annular vessels* (Fig. 207, *B*); while others, and among them the largest, have numerous thin spots in their walls which look like dots of various sizes, and these are the *dotted* or *pitted vessels*, often called *dotted ducts* (Fig. 207, *C*). These pitted vessels are often very large, their openings being visible to the naked eye in the cross-section of oak wood.

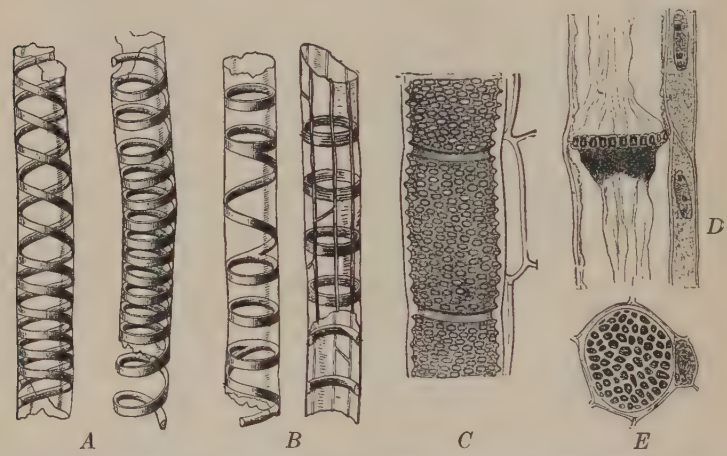


FIG. 207. — Vessels: *A*, spiral vessels; *B*, annular vessels; *C*, pitted vessel ("dotted duct"); *D*, sieve vessel; *E*, a sieve-plate. — *A* and *B* after BONNIER and SABLON, *C* after DEBARY, and *D* after STRASBURGER.

The cells of the bast that conduct prepared food are called *sieve vessels*, because in their walls, usually the end walls, there appear areas full of perforations, like the lid of a pepper-box, these areas being called *sieve-plates* (Fig. 207, *D* and *E*).

A prominent feature of such stems is that they can increase in diameter. If the stem lasts only one growing season, that is, if it is an *annual*, there is no increase in diameter; but if it lasts through several seasons, that is, if it is a *perennial*, it increases in diameter from year to year. Naturally, annual stems belong to herbs and perennial

stems to shrubs and trees. Taking the trees as an illustration, the increase in diameter occurs as follows. Between the xylem and the phloem of each bundle is a layer of very active cells called the *cambium* (Fig. 206), which soon extends across the intervening pith rays (Fig. 205), and so forms a complete cylinder of cambium. This cambium has the power of adding new xylem cells to the outer surface of the xylem, and new phloem cells to the inner surface of the phloem, as well as of adding to the pith rays where it traverses them. In this way a new layer of wood is laid down on the outside of the old wood; and usually these layers, added year after year, are so distinct that a section of wood shows a series of concentric rings (Fig. 208). Ordinarily one such layer is added each year, and hence the layers are called *annual rings*. The age of a tree is usually estimated by counting these rings, but occasionally more than one ring may be added during a single year. The new layers added to the phloem are not persistent; but the xylem accumulates year after year, until in an ordinary tree the stem is a great mass of xylem covered with thin layers of phloem and cortex. It is this mass of wood that supplies our lumber.

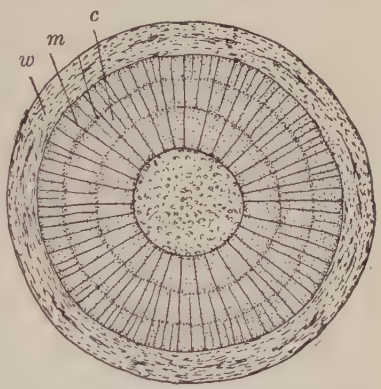


FIG. 208. — Cross-section of a branch of box-elder three years old, showing three annual rings in the vascular cylinder; the radiating lines (*m*) that cross the vascular cylinder (*w*) represent the pith rays, the principal ones extending from pith to cortex (*c*).

This annual increase in diameter enables the tree to put out an increased number of branches, and hence leaves, each succeeding year, so that its capacity for leaf-work becomes greater year after year. A reason for this is that since

xylem is conducting water to the leaves, the new layers enable it to conduct more water, and more leaves can be supplied.

When a stem increases in diameter, it is very seldom that the epidermis grows in proportion. Hence it is usually sloughed off and a new protective covering is developed by the cortex. Either the outermost layer of the cortex or some deeper one becomes a cambium, which means that it is able to form new cells. This cambium is called the *cork cambium*, since it forms at its outer surface layer after layer of cork cells, which are peculiarly resistant to water. If the cork cambium is formed deep in the cortex, all the cells outside of it die, since they are cut off from the water supply in the plant. The cork cambium is often renewed year after year, and two prominent kinds of bark are formed. In some cases the successive cork cambiums form zones completely about the stem, and the cork is then deposited in concentric layers, forming the ringed bark. Such bark often becomes very thick, and the surface becomes seamed or furrowed. In the cork oak, for example, there is a very great accumulation of cork, which is stripped off in sheets, from which corks of commerce are made. In other cases the successive cork cambiums, instead of passing completely around the stem, run into the next outer one, thus cutting out segments which presently loosen and flake off, forming scaly bark, as in hickory, apple, etc.

The layers of cork and other cells that may lie outside of the cork cambium form the *outer bark*, which is dead and dry. The tissues between the cork cambium and the cambium of the vascular cylinder, that is, more or less of the cortex and all of the phloem, form the *inner bark*, which contains some living cells. To remove the outer bark does not injure a tree; but removing the inner bark kills it, because it interrupts the work of conduction carried on by the sieve vessels. In the process known as *girdling*, not only

is the bark cut through, but the young wood is cut into. This interferes with the movement of water up the stem as well as with conduction by the sieve-vessels. If a small portion of the bark is removed, the incision extending only to the wood, as in the making of inscriptions on trees, the wound is healed, unless too large, by the growth of tissue from all sides until it is closed over. In this new tissue a cork cambium is developed, and presently there may be no surface indication of the wound. But if the wound has gone deeper and entered the wood, the record of it may always be found in the wood by removing the bark. In this way old inscriptions have often been uncovered.

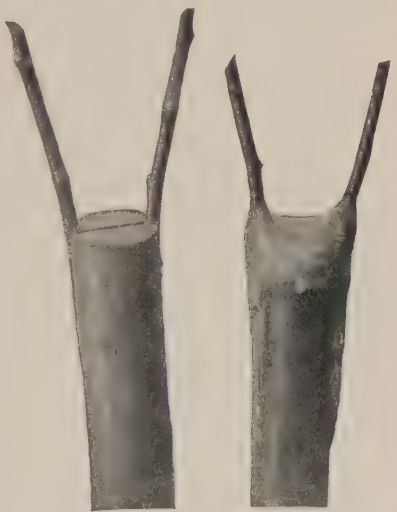


Fig. 209. — Cleft-grafting, showing scions in place (*A*) and the wound sealed with clay or wax (*B*).

The well-known operation of *grafting* depends upon the ability of plants to heal wounds. The plant upon which the operation is performed is called the *stock*, and the twig grafted into it the *scion*. An ordinary method, called *cleft-grafting*, is to cut off the stem or a branch of the stock, split the stump, insert into the cleft the wedge-shaped end of the scion, and seal up the wound with wax or clay (Fig. 209). The cambiums of the stock and the scion must be put into contact at some point; and hence it is usual to insert a scion in each side of the cleft, since the cambium of the stock is comparatively near the surface. The cambiums of stock and scion unite, the wound heals, and the scion

becomes as closely related to the activities of the stock plant as are the ordinary branches. The scions are usually cut in the fall, after the leaves have fallen, are kept through the winter in moist soil or sand, and the grafting is done in the spring. A number of important things are secured by grafting, but chief among them is the propagation of useful varieties with certainty and with a great saving of time, as compared with their propagation from the seed.

In Monocotyledons the vascular bundles of the stem are not arranged so as to form a hollow cylinder, but are more or less irregularly scattered, as may be seen in a cross-section of a corn-stalk (Fig. 210). As a consequence, there is no inclosing of a definite pith, nor is there any distinctly bounded cortex. In the bundles there is no cambium, and therefore new wood and bast cannot be added to the old, so that in the trees there is no annual increase in diameter; and this means that there is no branching and no increased foliage from year to year. A palm well illustrates this habit, with its columnar, unbranching trunk, and its crown of leaves, which continue about the same in number each year.

Fig. 210. — Cross and longitudinal sections of a corn-stalk, showing the scattered vascular bundles.

134. **Ascent of sap.** — The water entering the plant by the roots and moving upward through the stem is usually called *sap*. It is not pure water, but contains certain soil substances dissolved in it. In low plants, as most annuals, the ascent of sap requires no special explanation; but in plants such as trees, in which the crown of leaves is many feet above the soil, the case is very different. Several explanations of the ascent of sap in trees have been suggested,

and all of the older ones have been disproved, so that we are still waiting for an explanation that will stand the test of experiment.

That the path of ascent is through the vessels of the xylem, and not through cortex or phloem or pith, may be demonstrated by a simple experiment. A stem of corn or sunflower or balsam is cut off and placed in water for an hour. Then it is transferred to a vessel containing water stained with cheap red ink (a solution of eosin), and exposed to diffuse light. A few hours later, sections of the stem will show the xylem vessels stained red, the ascending water having stained its path. Of course the stain may spread somewhat into adjacent cells. It must be remembered that the xylem vessels are not living cells when they become the best water-carriers, so that the movement of water through them is not like the movement of water from one living cell to another. When the great distance to be traversed by water in a tall tree is considered, this movement of water through a system of dead cells is a very important fact to explain.

In most trees, as the mass of wood increases in diameter, the ascending sap abandons the inner (older) wood and moves only through the newer wood. This results in a different appearance of the two regions, the old central wood, abandoned by the sap, becoming darker and often characteristically colored (*heart wood*), and the younger outer wood, used by the sap, being lighter colored (*sap wood*). Trees vary greatly in the relative thickness of the sap wood; for example, in the beech it is a thick zone, while in the oak it is a narrow one. In successful girdling this must be taken into account, since an incision which would cut off the water supply of an oak sufficiently to kill it would not kill a beech.

The rate of movement of the ascending sap of course varies with different plants and different conditions. In the pumpkin-vine, in which the movement is very rapid, it has been

found to reach about twenty feet an hour. It is estimated that in ordinary broad-leaved trees the rate is probably three to six feet an hour.

If certain stems are cut off near the ground, it is observed that after a short time the sap begins to ooze out, a phenomenon that is often called "bleeding." In some woody plants, as grape-vines and birches, the sap flows out with considerable force, indicating some pressure below, which is called *root-pressure*. While root-pressure may force the sap into the stem, it is entirely inadequate to force it to the top of a tree.

FIG. 211. — Scarlet runner bean marked with a scale of five millimeter intervals and photographed after forty-eight hours; the lines closest together show the original spacing.

The so-called maple sap obtained from the sugar maple is an interesting illustration of the use of sap that accumulates in a woody stem in the spring. At that time the water has no opportunity to escape through leaf transpiration; so the wood becomes gorged with sap, which can be drawn off by boring into the wood and inserting spiles. The characteristic sugar has been obtained by the sap from food stored in the stem, notably in the older wood.

135. **Growth in length.** — Growth in length begins at the tip of the stem by the formation of new cells, which are organized into the alternating nodes and internodes. When these regions are first formed, the internodes are very short, and their subsequent elongation, separating the nodes, is the chief cause of the lengthening of the stem. Internodes are able to elongate for only a certain time, so that the

elongating portion of a stem does not often extend more than ten to twenty inches. Seedlings such as those of the bean should be cultivated, and the region of growth, the region of greatest growth, and the rate of growth determined. To do this, each internode is marked with equally spaced lines in India ink, and measuring these spaces at intervals

Fig. 212. — Axillary (and therefore branch) thorns: *A*, honey locust; *B*, hawthorn.

of one or two days will determine the facts referred to above (Fig. 211).

136. **Subterranean stems.** — Since stems (or branches) usually bear foliage leaves, any stem which does not is spoken of as "modified." For example, branches that become thorns (Fig. 212), tendrils (Fig. 213), leaf-like structures (Fig. 193), etc., are thought of as stems diverted from their ordinary use.

The most common " modifications " of the stem are those which arise when it is an underground structure, and thickened subterranean stems are not only common among plants,

FIG. 213. — Plants of passion-flower showing axillary (and therefore branch) tendrils.

but also are often of great use to man. Since the stem is primarily a leaf-bearing structure, it continues to bear leaves when underground, but often these leaves are either reduced in size so as to be mere rudiments, or are used in

FIG. 214. — Rootstock of a fern bearing young leaves.

FIG. 215. — Rootstock of a rush (*Juncus*), showing how it advances beneath the ground and sends up a succession of branches; the breaking up of such a rootstock only results in separate individuals.

some other way than as foliage. A stem and its leaves taken together constitute the *shoot* (as contrasted with the root), and since both must be considered in connection with the subterranean habit, the shoot, rather than the stem alone, will be discussed. A subterranean shoot may be distinguished from a root not only by the leaves (or structures representing leaves) it bears, but also by its internal structure, which is very different from that of a root, as will appear in the next chapter. In general, the subterranean shoot

FIG. 216. — Rootstock of Solomon's seal, showing terminal bud, the base of this year's aerial branch, and scars of the branches of three preceding years. — After GRAY.

is used for food storage, and the three following kinds are the most common.

(1) *Rootstock.* — This is probably the most common form of subterranean stem (also called a *rhizome*). It is usually horizontal, more or less elongated, and usually much thickened for food storage (Fig. 214). It advances through the soil year after year, often branching, sending out roots beneath and leaf-bearing branches into the air. As it continues to grow at the apex, it gradually dies behind, thus isolating branches in the case of branching rootstocks. It is a very efficient method for the spreading of plants and is extensively used by grasses in covering areas and forming turf. The persistent continuance of some weeds, especially certain grasses and sedges, that infest lawns and meadows, is due to this habit (Fig. 215). It is impossible to remove from the soil all of the indefinitely branching rootstocks,

and any nodes that remain are able to send up fresh crops of aerial branches. In many cases only a single aerial branch is sent up each year, as in wild ginger, Solomon's seal (Fig. 216), iris, bloodroot, etc.; in others, leaves and flowers may be sent up separately by the rootstock. In the common ferns, the so-called fronds are simply large leaves developed directly by the rootstock (Fig. 214). Perhaps even more familiar is the extensive rootstock system of the water-lilies, from which arise the leaves with large floating blades (pads). It is evident that a rootstock does not necessarily bear only scale leaves, but it may develop also leaves that

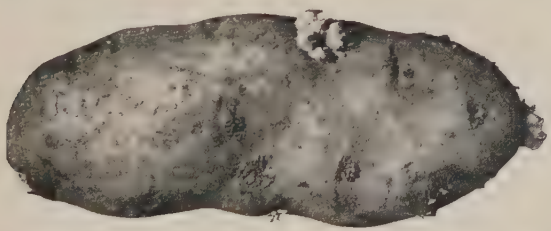


Fig. 217. — Potato tuber, showing "eyes" (scale leaves with their axillary buds).

become aerial, and in that case they are usually large. In plants possessing rootstocks, the subterranean stems are perennial, while the aerial parts may be annual.

(2) *Tuber.* — In some plants the ends of underground stems or branches become very much enlarged in connection with food storage. These enlargements are called *tubers*, the best-known illustration being the common potato (Fig. 217). That it is a stem structure is evident from the fact that it bears very much reduced leaves, in the axils of which are buds, the so-called "eyes." Abnormally developed potatoes often show the shoot character of the tuber very plainly, and in the case of potatoes sprouting it is evident that the eyes have developed into branches. In planting potatoes, as has been said, advantage is taken of the fact

that any node placed in proper conditions may strike root and put out a branch. Heaping up the soil ("hilling") about the base of the potato plant induces the formation of more of the subterranean tuber-bearing branches. In the tuber called Jerusalem artichoke, which is developed by the subterranean stems of a kind of sunflower, the nodes of the stem and the buds of branches are more conspicuous than in the potato. Fleshy roots, such as those of the sweet potato, should not be confused with tubers.

Fig. 218. — The scaly bulb of a lily.

(3) *Bulb.* — In some plants the main stem is very short and is covered by numerous thickened, overlapping leaves or leaf bases (usually called scales), the whole structure being a *bulb*. Bulbs such as those of the lily, hyacinth, tulip, and onion are very familiar. In this case the food storage is chiefly in the scales. *Scaly bulbs* are those in which the scales overlap, but are not broad enough to inwrap those within, as the lily bulb (Fig. 218); *coated bulbs* are those in which the broad scales completely inwrap those within, as the bulbs of onions and tulips. Small bulbs, called *bulblets*, are borne by some plants on parts above ground; as, for example, the bulblets that appear in the axils of the leaves of the tiger-lily and those that replace flower-buds in the common onion ("onion sets"). These bulblets, when planted, have the power of producing new plants, as do the subterranean bulbs.

These subterranean shoots, with their storage of reserve food, enable plants to put out their aerial parts with remarkable promptness and develop them with great rapidity. As an illustration of a situation in which this ability is of great advantage to plants, the *vernal habit* may be mentioned.

It is a matter of common observation that the rich display of spring flowers occurs in forests and wooded glens before the trees come into full foliage. The working season of these spring plants is between the beginning of the growing season and the full forest foliage, and the subterranean shoots enable them to send up their aerial parts with great rapidity. After the forest leaves are fully developed, the available light for work beneath the forest crown diminishes, the spring flowers disappear, and the short period of activity does not return until the next season.

Another situation in which speed of development is of great advantage to the plant is in regions in which there is a short rainy season and a long dry season. In such regions the annuals spring up with remarkable rapidity, and in most cases this is made possible by food storage in underground stems.

137. **Summary.** — The most important fact about a stem is that it produces and displays leaves. The nodes not only produce leaves, but also branches, and if the conditions favor it, they can produce roots also; therefore it is possible to reproduce a whole plant from a node, a fact that is taken advantage of in the propagation of many plants.

The vascular system forms a hollow cylinder in the stems of Gymnosperms and Dicotyledons, a cylinder that incloses pith and is surrounded by cortex. The two regions of the vascular cylinder are xylem and phloem, and in Gymnosperms and Dicotyledons the xylem is next to the pith and the phloem next to the cortex. A notable feature of such a stem is the presence of the cambium between the phloem and xylem, which adds new elements to each region. The additions to the xylem in the case of perennial stems (notably trees) result in an annual increase of wood, which usually appears as annual rings. This yearly increase in the capacity for carrying water is associated with the possibility of an annual increase of branches and leaves.

When a stem increases in diameter by the annual increase of xylem, the epidermis usually does not keep pace with it and is sloughed off. In any event, a cambium appears in the cortex and produces cork cells that form a most efficient protective jacket and that give character to what is called "bark."

Subterranean stems can be distinguished from roots by the presence of nodes bearing leaves, or at least rudiments of leaves. The subterranean habit is often associated with food storage, the significance of which is that it enables the plant to develop its aerial parts with great rapidity, and thus to make the most of a short season. This is one of the chief reasons why rootstocks, tubers, and bulbs are used in the propagation of cultivated plants, new plants being obtained much more speedily than by means of seeds.

CHAPTER XIII

ROOTS

138. **General character.** — Roots are thought of as structures related to the soil. This is true of most roots, and it is certainly true of the roots of those plants we cultivate.

FIG. 219. — Roots: *A*, dandelion with tap-root; *B*, grass with cluster of fibrous roots.

However, there are also water roots and air roots, so that the soil-relation is not the only one for roots, but this presentation will be restricted chiefly to soil roots.

Roots differ from subterranean stems even in external appearance, since they do not bear leaves or scales and do not have nodes. It should be remembered that roots are produced not only by the hypocotyl (§ 113, p. 180), but also by the nodes of stems. It is convenient to distinguish these two origins by calling the roots developed by the embryo *primary roots*, and those not developed by the embryo *secondary roots*. It has been observed (§ 136, p. 248) how subterranean stems, prostrate stems, and even erect stems "strike root" from the nodes, and such

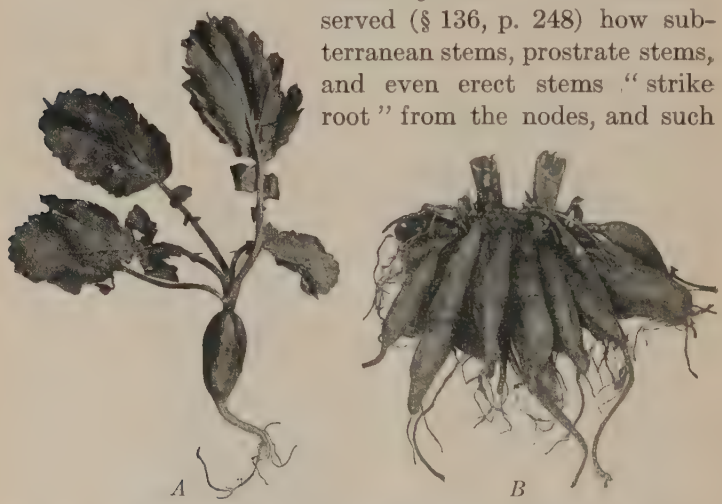


FIG. 220. — Fleshy roots; *A*, radish with fleshy tap-root; *B*, dahlia with cluster of fleshy roots.

secondary roots are the only roots of many plants. For example, when a new plant is developed by "layering" a raspberry (§ 131, p. 232), or planting a "slip" or "cutting" from a grape-vine, or planting slices of a potato tuber, secondary roots are the only kind possible, for the new plants are not produced by seeds.

The primary root developed by the hypocotyl may continue as a conspicuous, vertically descending axis that gives off small branches (Fig. 219, *A*); or it may break up at once

into a cluster of branches (Fig. 219, *B*). In the former case, the plant is said to have a *tap-root;* and in the latter case, when, as in grasses, the clustered branches are slender, the plant is said to have *fibrous roots.* In both cases the root may become enlarged in connection with food storage, and many of our common vegetables are such thickened roots. For example, radish (Fig. 220, *A*), turnip, and parsnip are thickened tap-roots; while sweet potatoes are the thickened branches of a cluster of roots, as in the dahlia (Fig. 220, *B*). It is evident that thickened roots, just as thickened underground stems (§ 136, p. 250), enable the plant to develop its aerial parts much more quickly than by the method of seed-germination.

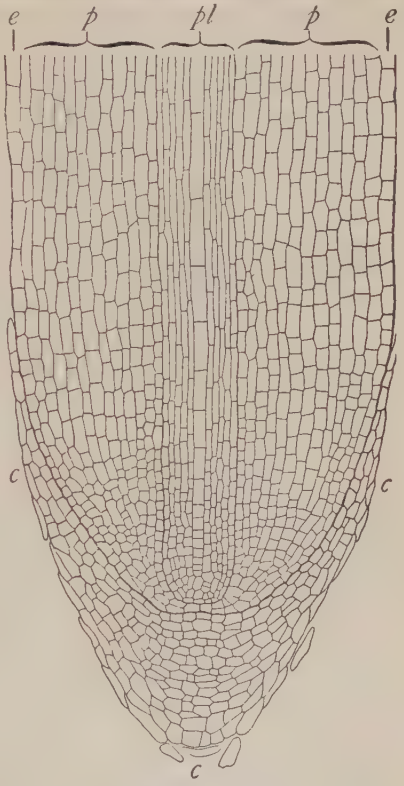


Fig. 221. — Longitudinal section through root-tip of spiderwort, showing central vascular cylinder (*pl*), cortex (*p*), epidermis (*e*), and root-cap (*c*).

139. **Root-cap.**— The growing tip of each root and rootlet is protected by a cap of cells called the *root-cap* (Fig. 221, *c*). This root-cap consists of several layers of cells, the outer ones gradually dying or being worn away as the tip of the root pushes through the soil, and being replaced by new layers

which are continually forming beneath. In some plants the root-cap is very easily seen as a conical thickening at the tip of the root; in others it can be demonstrated only by examining under the microscope longitudinal sections through the root-tip. The presence of such a protective cap in the root is in strong contrast with the stem, whose growing tips are protected by overlapping leaves.

140. **Root-hairs.** — A short distance behind the root-cap the surface of the root becomes covered by a more or less dense growth of hairs, known as *root-hairs* (Fig. 222). These hairs are outgrowths, sometimes very long ones, from the epidermal cells, a single cell producing a single root-hair. In fact, the root-hair is only an extended part of the epidermal cell. The root receives water and materials dissolved in it from the soil, and the root-hairs enormously increase the receiving surface. Root-hairs do not last very long; but new hairs are being put out by the elongating root as the old ones behind die, so that there is always a zone of active root-hairs near the tip, but none on the older parts of the root.

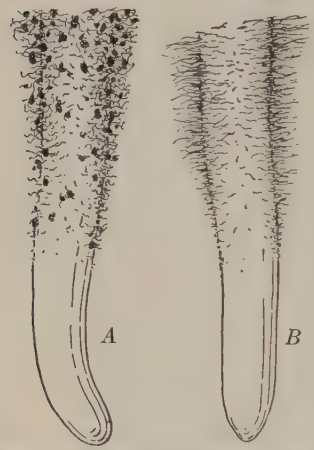


FIG. 222. — Root tips of corn, showing root-hairs and their position in reference to the growing tip.

141. **Internal structure.** — A cross-section of a young root shows two prominent regions (Fig. 223). In the centre is a solid vascular cylinder, often called the *central axis*. It will be remembered that in the stems of Dicotyledons and Gymnosperms (§ 133, p. 236) the vascular cylinder is hollow, inclosing pith. Investing the solid vascular cylinder of the root is the cortex, which often can be stripped from the

central axis like a spongy bark. If the section has passed through the zone of root-hairs, they can be seen coming from the epidermal cells. A longitudinal section of a root-tip, in which these regions are very young, is shown in Fig. 221.

The xylem and phloem of the vascular cylinder of the root do not hold the same relation to each other as in the stem (§ 133, p. 237). The vascular cylinder, instead of being made up of vascular bundles with xylem toward the centre and phloem toward the outside, as in the stems of Seed-plants, is made up of xylem and phloem strands alternating with each other around the centre (Fig. 223). The xylem strands radiate from the centre like the spokes of a wheel, and the phloem strands are between these spokes near their outer ends. This arrangement of xylem and phloem is peculiar to roots.

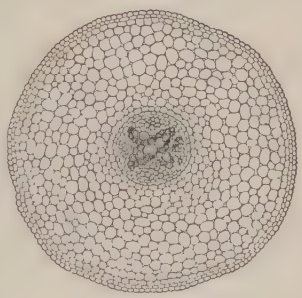


FIG. 223. — Cross-section of a young root, showing the solid vascular cylinder, the extensive cortex, and the epidermis; observe that the xylem extends from the centre in four strands, between which the phloem strands are seen.

When roots increase in diameter, a cambium soon begins to form new xylem and phloem, as in the stems that increase in diameter (§ 133, p. 239). The new xylem, however, is not formed in connection with the old wood, but just within the phloem, that is, farther in between the "spokes" of old wood, resulting in bundles like those of the stem (Fig. 224). In this way a thickened vascular cylinder is formed, like that of stems that increase in diameter; and presently the cross-section of the root resembles that of the stem. It is evident (Fig. 224) that the principal pith rays that traverse the wood zone formed by the cambium (secondary wood) extend inward to the original radiating strands of wood (primary

wood) that alternate with the original strands of phloem. The vascular bundles of the root connect with those of the stem, and these in turn with those of the leaves, so that throughout the whole plant there is a continuous vascular system.

The origin of the branches of roots is very different from that of stems. In a stem the branch begins at the outer part of the cortex, but in the root it begins at the surface of

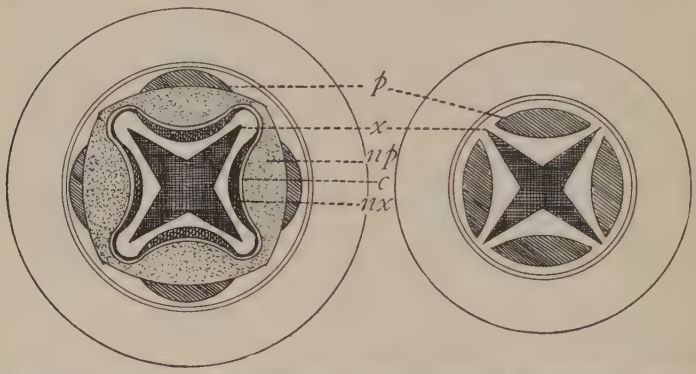


FIG. 224. — Diagram to show how roots increase in diameter: *A* represents cross-section of a young root in which four phloem strands (*p*) alternate with four xylem strands (*x*); *B* represents an older root in which there is a continuous zone of cambium (*c*) that is forming on the outside new phloem (*np*) in contact with the old (*p*), and on the inside new xylem (*nx*) alternating with the old (*x*).

the vascular cylinder and breaks through the cortex (Fig. 225). If the cortex of a root be stripped off, the branches will be found attached to the central axis, and the perforations made by the branches through the cortex can be seen.

142. **Growth in length.** — The elongating region of the root is much more restricted than that of the stem. It was stated (§ 135, p. 244) that the elongating region of a stem may extend ten or twenty inches from the tip, or even more; but the elongating region of a root is hardly ever more than two-fifths of an inch, and often not more than half of that. The region of elongation and of greatest elongation should

be determined by using such seedlings as those of peas, beans, and corn. When the young roots have become a half to one inch long, mark as delicately as possible in India ink with a soft, camel's hair brush a series of equally spaced lines, beginning at the tip. Observations at the end of twenty-four to forty-eight hours will reveal the region of elongation and of greatest elongation (Fig. 226).

Fig. 225. — Longitudinal section of root of arrow-leaf, showing the branches starting from the vascular cylinder and penetrating the cortex.

143. **The soil.** — The soil is too commonly thought of as merely an accumulation of "dirt," from which plants can obtain "food." It has been pointed out in preceding chapters that ordinary plants do not obtain food from the soil, but that they do obtain certain materials used in food-manufacture. It now remains to consider whether the soil is merely "dirt."

Soil is finely divided rock (mineral) material, which in "rich" soil is mixed with more or less organic material derived from the broken-down bodies or waste products of plants and animals. It is the organic material that makes soils dark, and when there is a considerable amount of this, as in the upper soil of forests, the soil is called *humus* (often "vegetable mould" or "leaf mould"). Soil, therefore, is a mixture of certain mineral (inorganic) and organic materials. These materials must include certain chemical substances that plants need, and in general all soils contain these substances. This is indicated by the fact that almost all soils in nature are covered by vegetation, and even in the desert of Sahara, reputed to have the most "sterile" of soils, the breaking through to the surface of a spring of water results in an "oasis" with luxuriant vegetation. This indicates

that the chemical composition of all soils is appropriate for plants, and that the differences between soils is not so much a question of proper or improper chemical constitution as of something else. The chemical composition of soils is uniformly appropriate for plants in the same general sense that the air is uniformly appropriate for them. It is sometimes said that the chemical composition of soils " makes no difference," but this does not mean that it is not extremely important, any more than the statement that the air " makes no difference " would indicate that the air is not important. It makes no difference simply because it is always present.

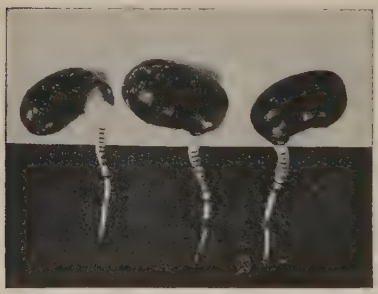


Fig. 226. — Roots of scarlet runner bean marked with lines one millimeter apart and photographed after forty-eight hours.

The great differences among soils have to do with their power to handle water, and this is a physical property of the soil rather than a question of chemical composition. The power of a soil to receive and to retain water is a very important consideration in connection with plants. For example, it is evident that the receptive power of sand is high, but its retentive power is low; while in the case of clay the reverse is true. One of the great advantages of humus is that its receptive and retentive powers are better balanced than in sand and clay. It is easy to devise a series of experiments that will show in a rough way the comparative receptive and retentive powers of these three types of soil. It has been shown also that, for any given soil, the more finely the particles are divided the better it is for plants. When the soil is turned up with plough or spade, it is dried by the air and pulverized and so put in better physical condition for hand-

ling water. It is evident that in considering the relation of soil to plants, not only the surface soil must be considered, but also the soil beneath (*subsoil*). For example, if humus rests on sand, the water will drain away much more rapidly than if humus rests on clay.

It is necessary to understand the physical structure of the soil in relation to water. However fine the particles of soil may be, they never fit together in close contact, so that there are open spaces everywhere among them. Immediately after a soaking rain these spaces are full of water, but if the soil is one that drains easily, the water gradually disappears from the spaces, and the larger ones are occupied by air. In addition to this occasional supply of water, each particle of soil is invested by a thin film of water, which adheres to it closely, and which never entirely disappears even in the driest soil. It is the water of the adherent films that enters the roots, and not the " free water " that may occur in the spaces between the soil particles. These spaces should be kept free of water, that the air may " circulate." Roots are living structures, and they need air just as the aerial parts of the plant need it. This is the reason why good drainage is necessary in a cultivated field, for drainage carries off the free water which would drown the roots, but it does not carry off the water of the films. The ideal arrangement is for a well-aerated soil (with no free water) to rest upon a subsoil that holds water (like clay), so that the rain water may " soak through " the aerated soil, and yet be held near enough to it so that the films may be supplied as they become thin. It is this physical condition of the soil that the farmer must look after with great care.

But the soil is not merely a chemical laboratory supplying certain substances, and a physical laboratory making water and air available at the same time, but also an extensive biological laboratory. In the chapter dealing with the bacteria (§ 37, p. 46), the extremely important work of soil

bacteria was indicated. Certain very important substances needed by plants, especially substances containing nitrogen, are put into usable form by these bacteria. It was stated that when by removing crops these substances become so diminished in amount that the soil is said to become " poor," they may accumulate again by letting the poor field " lie fallow " until the bacteria have enriched it, or by a " rotation of crops " by means of which the same result is secured more rapidly. This shows that the soil is the home of a world of bacteria, which by their life processes are putting materials into available form for higher plants.

In addition to the soil bacteria, there are the thready Fungi called mycorhiza (§ 40, p. 61), which become attached to the roots of plants and extend indefinitely through the soil, forming a wide ranging system of tubes through which water may be brought to the roots from regions of the soil far beyond the reach of the roots themselves.

The picture of the soil, therefore, is that of a complex physical, chemical, and biological laboratory, full of activities of all kinds. It is this delicate and sensitive laboratory that men undertake to use and know very little about. They seek to " improve " it by putting on all sorts of " fertilizers." Many of the fertilizers do some good; some of them kill the bacterial life, and then the dead soil must be kept " fertilized "; none of them is used with sufficient knowledge of the needs of the soil. What any given soil needs depends upon so many things that there must be developed soil specialists, who will diagnose soil conditions just as a medical specialist is necessary to diagnose conditions of the human body. Especially is this true for soils that are " sick," for then the soil is just as complex a patient as is a sick person.

144. **Entrance of water.** — To obtain water from the soil, the root not only often branches profusely, but also develops the root-hairs described above (§ 140, p. 256). Only in the younger portions of the root, that is, in the general region of

the root-hairs, does the water enter freely. The root-hairs push out among the soil particles and come into very close contact with them, the particles sometimes being embedded in the wall of the hair (Fig. 227). In this way the films of water adhering to each soil particle are closely applied to the hair, and water passes from them through the wall of the hair into its cavity, and so into the plant. As water enters from the films they become thinner, and this loss is supplied from neighboring films. In this way a flow from regions of the soil deeper and more distant than those to which the root reaches is set up toward the films losing water. The water supply may not be able to make good such loss indefinitely; and if so, the films gradually become thinner, until a point is reached when the root-hair can obtain no more water, the thin film holding tenaciously to its particle of soil. After the roots have obtained all the water they can from the soil, and it seems perfectly dry, it still contains two to twelve per cent of water in the form of films.

Fig. 227. — Root-hair of wheat, which is shown to be an outgrowth of an epidermal cell in close contact with the soil particles.

The water thus obtained by the root-hairs passes inward through the cortex and enters the wood of the vascular cylinder, and then is free to ascend to the wood of the stem, and so to the leaves.

145. **Entrance of salts.** — In addition to water, the soil supplies chemical substances in the form of salts, from which the plant obtains certain elements that it needs in the manufacture of proteins, as nitrogen, sulphur, and phosphorus.

The most important salts of the soil, therefore, are nitrates, sulphates, and phosphates. In order to enter the root, these salts must be in solution, so that they pass in dissolved in the water that enters from the films about the soil particles. These films, adherent to the soil particles, naturally dissolve any soil material that is soluble in water. It is very important to know, however, that these dissolved salts are not simply swept in by the moving water, for water and salts move independently.

The rate at which water enters the plant depends upon the rate at which the plant is losing water; and so the rate at which a soil salt enters a plant depends upon the rate at which the plant is using it. For example, if a soil salt, called *A*, is being used up constantly in the plant by being put into new compounds, *A* will continue to enter from the soil. If, on the other hand, a soil-salt, called *B*, is not being used by the plant, it accumulates in the plant until the solution of it in the plant is as concentrated as the solution of it in the soil films, and then no more of it can enter, even if it does present itself to the root in solution. This is what was once called the "selective power" of the root, by which was implied that the root has some mysterious power of selecting from the soil just what it needs. In our illustration, the root would seem to have the power of selecting *A* and rejecting *B*, but it is obvious that it is explained by a well-known law of physics (osmosis).[1] It follows that when any soil-salt is observed to accumulate in a plant, it is an indication that the

[1] Osmosis may be defined briefly by the following illustration: If a membrane (like a cell-wall) forms a partition between two masses of water, and sugar is dissolved in the water on one side, it will pass through the membrane until the solution on both sides is of the same concentration. Therefore, whenever one cell contains a salt in greater concentration than a neighboring cell, there will be a movement of the salt from the former cell into the latter; but if the concentrations in the two cells are the same, there will be no movement.

plant is not using it; and that the soil-salts the plant is using are not apt to be found in it. This will explain why the chemical analysis of a plant does not detect what it is using from the soil, but only what it cannot use.

A distinction must be made between the entrance of the salts of the soil into the root, and their movement through the vascular system (xylem) of the root, stem, and leaves. The entrance is through living cells until the xylem is reached, and then the movement is through dead cells. As has been said, a salt enters a living cell only when the water of the cell is poorer in the salt than the water outside (osmosis); but in dead tissue (as the water-carrying xylem) osmosis does not work, and the salts dissolved in the water are carried along with it. When they reach their destination, as the mesophyll cells of a leaf, they must pass from the xylem (of the veins) into the working cells according to the law of osmosis. Therefore, salts *enter* the plant by the selective power of osmosis, they are *carried* through the xylem by the movement of water, and they are *delivered* to the working cells by the selective power of osmosis.

146. **Special forms of roots.** — Roots in soil serve the double purpose of anchoring the plant and receiving water, but certain roots hold other relations and need special mention.

(1) *Prop-roots.* — In certain plants roots are sent out from the stem or the branches, and finally reaching the ground establish the usual soil relations. Since these roots resemble braces or props, the name *prop-roots* has been applied to them (Fig. 228). A very common illustration is that of the corn-stalk, which sends out such roots from the lower nodes of the stem. More striking illustrations, however, are furnished by the banyan and the mangrove. The banyan sends down from its wide-spreading branches prop-roots, which are sometimes very numerous. When they enter the soil they often grow into large trunk-like supports, enabling the

branches to extend over an extraordinary area. There is record of a banyan cultivated in Ceylon with 350 large and 3000 small prop-roots, and able to cover a village of one hundred huts. The mangrove is found along tropical and subtropical seacoasts, and gradually advances into the shal-

FIG. 228. — A screw-pine with prop-roots. — Photograph by LAND at Orizaba, Mexico.

low water by dropping prop-roots from its branches and entangling the detritus (Fig. 229).

(2) *Water-roots.* — If a stem is floating, clusters of whitish thread-like rootlets usually put out from it and dangle in the water. Plants which ordinarily develop soil-roots, if brought into proper water relations, may develop water-roots. For

Fig. 229. — Mangroves, showing the numerous prop-roots.

instance, willows or other stream-bank plants may be so close to the water that some of the root system enters it. In such cases the numerous clustered roots show their water character. Sometimes root systems developing in the soil may enter tile drains, when water-roots will develop in such clusters as to choke the drains. The same bunching of water-roots may be noticed when a hyacinth bulb is grown in a vessel of water. It is evident that contact with abundant water modifies the formation of roots, both as to number and character.

Fig. 230. — An orchid with aerial roots.

(3) *Clinging roots.* — Such roots fasten the plant body to some support, and may be regarded as roots serving as tendrils. In the trumpet-creeper and poison-ivy these tendril-like roots cling to various supports, such as stone walls and tree trunks, by sending minute branches into the crevices. In such cases, however, the plant has also true soil roots.

(4) *Air-roots.* — Some plants have no soil connection at all. In the rainy tropics, where it is possible to obtain sufficient moisture from the air, there are many such plants, notable among which are the orchids, to be observed

in almost any greenhouse. Clinging to the trunks of trees, usually imitated in the greenhouse by nests of sticks, they send out long roots which dangle in the moist air (Fig. 230). Such plants are called *epiphytes*, the name indicating that they perch upon other plants and have no connection with the soil (Fig. 231). A very common epiphyte of our Southern states is the common long moss or black moss (although

FIG. 231. — A group of epiphytes in a tropical forest. — After KARSTEN and SCHENCK.

it is by no means a moss) that hangs in stringy masses from the branches of live-oaks and other trees (Fig. 232.)

147. **Summary.** — The root receives water and salts from the soil, and incidentally anchors the plant. The structure of its vascular cylinder is very different from that of the stem cylinder. The phloem does not occur between the xylem

and the cortex, but phloem strands alternate with xylem strands around the centre, so that both xylem and phloem are in contact with the cortex. It is evident that the xylem is to receive and conduct the water and salts from the soil, that these substances must pass through the cortex to reach the xylem, and that they must enter the root through the exposed epidermis and its array of root-hairs.

The soil is a complex chemical, physical, and biological laboratory, where materials are accumulated and put in

Fig. 232. — Live-oaks covered with "long moss."

available form for plants, and where hosts of bacteria and other fungi are working. The physical properties of the soil in receiving and retaining water, the necessity of drainage so that air may circulate through the soil freely, the adhesive films of water about the soil particles, the entrance into the roots of water from the films and not from the free water of the soil, are all physical features that must be kept in mind.

As the aerial parts of the plant are continually losing water, the water of the soil can always enter the root freely. The salts of the soil must be dissolved in the water before entering, and even when dissolved they can enter only in case they are being used by the plant and therefore changed.

CHAPTER XIV

PLANT ASSOCIATIONS

148. **General statement.** — In the preceding chapters plants have been studied as individuals that have certain structures and that live and work in certain conditions. There is another aspect of plants that must be considered, when one regards them as "clothing" the earth. This is the broadest view of plants, and it requires a great deal of training to appreciate it fully. The purpose of the present chapter, therefore, is not to discuss this subject, but to give the elementary student, with some knowledge of plants as individuals, a glimpse of it. The two aspects of plants referred to may be illustrated by the two methods of studying people: they may be studied as individuals engaged in various kinds of work, or they may be studied as groups associated in villages and cities. It is true that the earth is covered by individual plants, but it is also true that these plants are associated together in various ways, forming what may be called plant communities. It is this community life of plants that is to be considered in the present chapter.

149. **Plant associations.** — It is a fact of common observation that plants are not scattered indiscriminately over the surface of the earth, regardless of one another and of the conditions for growth. It is recognized, for example, that there are forests, prairies, plains, and swamps, each one of which represents an association of plants that characterizes it. Into each association certain plants are admitted, and from each association many plants are excluded. That is,

we have come to recognize that certain plants are naturally associated, because they grow in the same conditions. Any set of conditions for plants is said to be a *habitat*, that is, a place that certain plants inhabit. Therefore, each kind of habitat has its own association of plants, and a plant association may be defined as an association of plants growing together in the same habitat.

150. **Determining factors.** — Since different kinds of habitats are characterized by different kinds of plant associations, it is important to discover the things that make habitats different, that is, the factors that determine the character of a habitat in reference to plants. It must not be supposed that all the determining factors have been discovered or that the relative importance of those that are known is appreciated fully.

The most conspicuous determining factor, and perhaps the most important one, is *available water*, that is, water in a condition to be used by plants. The range of water-supply may be said to extend from 100 per cent, in which case the plants would be submerged, to 5 or even 2 per cent, in which case the habitat would be called a " desert." Plants differ as to the amount of water they must have, and therefore a plant that needs a habitat with at least a 50 per cent water-supply could not live in the habitats with a less supply, and might not be able to endure a much greater supply. In this way, the possible range of water-supply may be thought of as a violin string, which can be made to produce many different tones, and each " tone " in our range of water-supply stands for a different habitat and a different plant association.

Another determining factor is the *temperature*, and every one knows that some plants need more heat than others. The range of temperature in which plants can work may be stated roughly as extending from 120° F. to 32° F. (freezing point). Of course many plants can endure lower temperatures, for they survive the winters, but the temperature that deter-

mines a plant association is the working temperature. The range of temperature may be likened to a second violin string that can produce different tones, each temperature "tone" standing for a different plant association.

These two determining factors (water and temperature) introduce the idea of combinations of factors. For example, two violin strings make possible a far greater variety of tones when used in combination than when used singly. In the same way the combination of two determining factors multiplies plant habitats and associations. If there is a combination of maximum water-supply and maximum temperature, the plant association will be a tropical jungle; but if there is a combination of minimum water supply and maximum temperature, the habitat will be a desert. This indicates the numbers of different plant associations that various combinations of factors make possible.

Other determining factors, such as soil, light, wind, etc., have been studied, but they do not need to be discussed here. They suggest, however, that the different kinds of plant associations may be very numerous, for if a violin with two strings can make possible a large number of combinations, what must be the possible number of combinations when the violin has six or more (probably many more) strings? This simply means that each plant association has an individuality of its own, just as each town or city has its own individuality. Therefore, wherever one goes, he meets with new kinds of plant associations, just as he meets with new kinds of cities wherever he travels.

151. **Some features of a plant association.** — When a plant association is visited, it may be looked upon as a community whose population consists of plants. There are certain general features in the community life of such a population that become evident at once.

One of the most obvious facts is that certain individuals dominate and give tone to the community. For example,

a forest association is dominated by the trees, and often by one or two kinds of trees. This is so evident that most people think of a forest as consisting of trees alone, when in fact they are only part of a large population. In the same way, a meadow is dominated by grasses, so that to many it seems to be almost exclusively a grass population. Thus each association is apt to have its dominating individuals that characterize it. This fact has a very interesting corollary. The rest of the plant population must adjust itself to the dominant individuals. For example, in the forest population, the other plants must adjust themselves to the dominating trees. Very many of them are so constituted that they can live in the shade of trees; while others, like the "spring flowers," by means of underground storage of food in roots or stems, can spring up rapidly and come into flower in the short period between the first warm days of spring and the full foliage of the trees, thus finishing their work before the shade becomes dense.

Another notable feature of a plant community is that the nearest relatives are the keenest competitors. If a certain kind of plant has established itself in a community, it is very difficult for a nearly related plant to obtain a foothold. It must not be thought that the "competition" referred to, whatever it may be, is of the active sort, but the word at least figuratively describes a situation. This fact contains some very practical suggestions. Our worst "weeds" are not members of our native population, but immigrants. In various ways, the native plants of foreign countries become introduced into America. If they find near relatives in our native population, they are not heard of as weeds; but if they find no near relatives, they are probably freer from competition than they were in their native country, and may become a pest. The important suggestion, however, is that the more kinds of plants there are on a given area, the larger will be the total plant population. For

example, compare the number of individual plants in a well-kept corn-field, in which we are trying to cultivate as many individuals of one kind as possible, with the number of individuals (population) on an equal area in nature. In the former case, the individuals stand well apart and are comparatively few; while in the latter case they stand thickly together and are many times more numerous. In both cases, the plants are "doing well." The Chinese have taken advantage of this fact in their cultivation of plants, raising two or three different crops simultaneously on the same area, and thus increasing the total population and of course the total yield. In cultivating only one kind of plant at a time on an area, therefore, we are reducing the possible plant population to its minimum.

152. **Succession of plant associations.** — The most important fact in reference to a plant association is that it is not permanent on a given area. In general, when a plant association lives for a time upon an area, that area becomes increasingly unfavorable to it, until gradually it is succeeded by another plant association. Almost any plant association finally makes conditions unfit for itself, and at the same time more fit for some other association. This succession of plant associations may be illustrated by the succession of human communities. Pioneer conditions bring together a characteristic association of individuals, but the conditions do not remain pioneer, and become favorable for another association of individuals, and this kind of succession may go on, until the series of associations can be traced from the pioneer association to the metropolitan association. This means that each plant association can reveal the succession of associations that preceded it and also the succession of associations that will succeed it. In other words, the most important thing about a plant association is the history and prophecy it contains.

It is evident that there may be many kinds of succession,

dependent upon the habitat. The start may be on bare rock, on sand, on clay, in a drained swamp, or in an undrained swamp, and then each kind of succession will follow. It is also evident that the succession cannot go on indefinitely, but that some final association will be reached which is called the climax association, for that region. In general, some type of forest is the climax association, but there are obvious reasons why that type cannot be reached in certain regions.

153. **Forest succession.** — Since forests represent the most important natural vegetation, an illustration of forest succession will be given. It will serve to illustrate not only an important succession, but also the facts that must be considered in any effective study of forestry. One of the best known forest regions is the white pine region of Northern Michigan, from which the trees have been swept, with no thought of their continuance, and the evolution of this forest will indicate the forest problems in general.

The succession of plant associations which led up to the white pine forests started on sand, rock, clay, or in swamps, but the series beginning on a sandy beach will be used in the illustration. The first stage was the lower beach, washed by the summer waves, and therefore with no vegetation, but with an accumulation of sandy soil. The second stage was the middle beach, rising higher above the water, and therefore washed only by the larger winter waves. This freedom from waves during the summer permitted the growth of certain annual plants, whose bodies added some humus to the sand. The third stage was the fossil beach, that is, a beach that was once washed by the waves, but is now beyond their reach. This continual freedom from wave action permitted the growth of more plants, and therefore resulted in the accumulation of more humus, but the soil would still have looked rather bare, as the plants would not cover the surface. The fourth stage was made possible by the accu-

mulation of humus, and it is called the heath stage, for plants of the heath family and their associates occupied the ground. At this stage, for the first time, the plants covered the ground so thickly that competition among individuals began.

With the further accumulation of humus, the fifth stage became possible, that is, the pine forest stage. Gradually the pines invaded the heath, first the jack pine, then the red pine, and finally the white pine. It was at this stage that men caught the succession and destroyed the pines. When a forest fire swept through the pine forest, it not only checked the succession, but often set it back. If the fire was prolonged and intense, it not only destroyed trees, but also much of the humus, and in such a case the succession might be set back to the heath stage. This would mean a long accumulation of humus before the pine forest could come in again.

But the important fact is that the white pine forest is not the climax forest for that region, for it has the curious habit of what may be called race suicide. Its seeds do not germinate well and its seedlings do not thrive in the shade, so that when a deeply shaded white pine forest is established, it cannot perpetuate itself. But this shade is favorable to the seeds and seedlings of the maple and beech, and therefore these trees gradually supplant the white pine, and the maple-beech forest (a hard-wood forest) is the climax association for that region. It follows that the problem of forestry in the white pine region is not merely a fight against the devastation of men, but more fundamentally a fight against the race suicide of the white pines and against the encroachment of the hard-wood trees.

This is an illustration of but a single forest succession out of a great many that forestry must recognize. For example, in Oregon and Washington, where the conifer forests are so conspicuous, they are the climax type, and there is no danger of an invasion by hardwood trees. The conifers of that region

do not commit race suicide, and the deciduous (hard-wood) trees are not favored by the winter rains and dry summers.

154. **Some conspicuous plant associations.** — It has become customary to group all plant associations under three heads, based on the water-supply of the habitat. *Hydrophytes* ("water plants") are plants that grow in water or in very wet soil, and their associations are "hydrophytic associations." *Xerophytes* ("dry plants") are plants that grow in conditions of scanty water-supply, and their associations are "xerophytic associations." *Mesophytes* ("medium plants") are plants that grow in conditions of medium water-supply, and their associations are "mesophytic associations."

It should be noted that the mesophytic conditions are those used for cultivating plants, such land being said to be "arable." If the conditions are hydrophytic, the land is drained before cultivation; if the conditions are xerophytic and there is sufficient soil accumulation, the land is irrigated. The same processes are going on in nature. If a succession of societies starts in a pond or swamp (hydrophytic), the conditions gradually become more and more mesophytic, until finally mesophytic associations appear. If a succession starts on a bare rock or sand (xerophytic), through the accumulation of humus and the increase of shading, the conditions gradually become more and more mesophytic, until finally mesophytic associations appear. This means that where conditions are not mesophytic already, the natural succession of societies tends to make them so.

From what has been said of plant associations, it is evident that they are far too numerous to permit in this connection a description of even the most conspicuous ones. The best that can be done is to select from among the most conspicuous associations a few types that will emphasize what is meant by plant associations. It must be understood that this is not to be a study of these associations, for such study

requires a great deal of training, but it is to be merely an introduction to certain associations.

Along the low shores of small lakes, it is very common to

Fig. 233. — A reed swamp near Chicago.

see in the shallow margin a high fringe of reed-like plants, among which wild rice, bulrushes, and cat-tails dominate (Fig. 233). This kind of association is known as a *reed swamp*,

Fig. 234. — A swamp forest.

and its plants have been called the pioneers of land vegetation; for their growth and the entangled detritus make the water more and more shallow, until finally the reed plants are compelled to migrate into deeper water. In this way small lakes and ponds may become converted first into ordinary swamps, and finally into wet meadows. Instances of nearly reclaimed ponds may be found, where bulrushes, cat-tails, and reed grasses still occupy certain wet spots, but are shut off from further migration.

In many regions, especially in our northern states, there is a peculiar kind of swamp association, characterized by the abundant growth of the bog moss or peat moss, and developed in undrained swamps. Growing out of the springy moss turf there are numerous peculiar plants, such as heaths and orchids, and the curious carnivorous plants (§ 127, p. 218). Often trees encroach upon peat bogs and a *swamp forest* is the result. The chief types in this case are the conifers, and on this bog-moss foundation there occur larches, certain hemlocks and pines, junipers, etc. The larch or tamarack is a very common swamp tree of the northern regions, usually occurring in small patches; while the larger swamp forests are composed of dense growths of hemlocks, pines, etc. (Fig. 234).

The two illustrations just given are from hydrophytic associations, but the swamp forest is approaching the mesophytic conditions.

Plant associations inhabiting dry, sandy ground are very common, but perhaps the most extreme type of sand associations is that which inhabits dunes, and may be called *dune associations*. On certain borders of the Great Lakes and of sea coasts, beyond the beach, the dunes occur. They are billows of sand formed by the prevailing winds, and in many cases they are continually changing their form and are frequently moving landward (Fig. 235). In the case of these moving dunes a peculiar type of vegetation is demanded,

and very few plants are able to live in such severe conditions.

One of the greatest of plant associations is that which occupies the *plains* in the interior of continents, where dry air and wind prevail. The plains of the United States extend from about the one-hundredth meridian westward to the foothills of the Rocky Mountains. Similar great areas

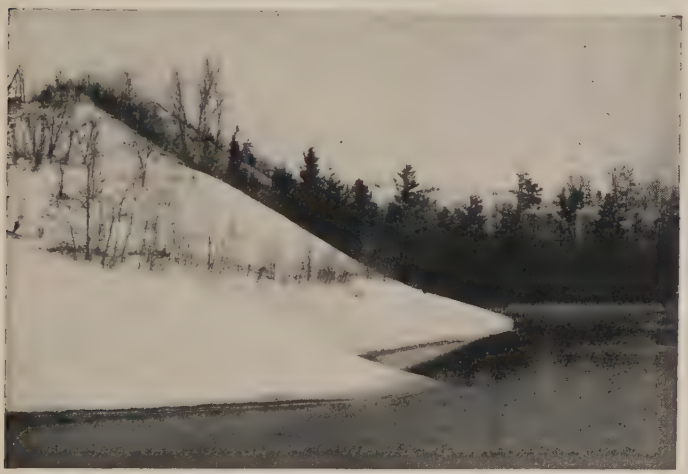


FIG. 235. — Dunes of Lake Michigan encroaching upon the land, in this case diverting Calumet River.

are represented by the steppes of Siberia, and in the interior of all continents. On the plains of the United States the characteristic plant forms are bunch-grasses (grasses that grow in tufts and do not form turf) and the low grayish shrubs called sagebrush.

In passing southward on the plains of the United States, the conditions are observed to become drier, until the *cactus deserts* are reached. This region begins in western Texas, New Mexico, Arizona, and southern California, and stretches far southward into Mexico. This vast arid region has de-

veloped a peculiar flora, which contains our most highly specialized drought plants. The numerous forms of cactus are the most characteristic, and associated with them are the yuccas and agaves. Not only is the equipment for checking transpiration and for retaining water of the most extreme kind, but also there is developed a remarkable armature of spines.

The dune associations, plains, and cactus deserts are illustrations of xerophytic associations, but even more extreme xerophytic conditions occur in connection with bare, exposed rocks, and in the subtropical desert regions (as the desert of Sahara).

Three conspicuous kinds of mesophytic associations may be selected as illustrations, associations that require a medium amount of moisture, a more or less evenly distributed precipitation, and a soil rich in humus.

A very characteristic mesophytic association is the *meadow*, by which is meant areas of natural meadow, not to be confused with artificial areas of the same name under the control of man. The appearance of such an area hardly needs description, as the vegetation is a well-known mixture of grasses and flowering herbs, the former usually predominating. Such meadows, of large or small extent, are very common in connection with forest areas and on the flood-plains of streams (Fig. 236).

The greatest meadows of the United States are the *prairies*, which extend in general from the Missouri eastward to the forest region of Illinois and Indiana. The vegetation of the prairies is usually composed of tufted grasses and perennial flowering herbs. Unfortunately, most of the natural prairie has been replaced by farms, and the characteristic prairie plants are not easily seen. The flowering herbs are often very tall and coarse, but have brilliant flowers, as asters, goldenrods, rosinweeds, lupines, etc. The origin of the prairie has long been a vexed question, which has usually

Fig. 236. — A small natural meadow surrounded by trees and shrubs. — After Schimper.

taken the form of an inquiry into the conditions which forbid the growth of a natural forest. Prairies are of two kinds at least; those due to soil conditions and those due to climatic conditions. The former are characteristic of the eastern prairie region, and appear in scattered patches through the forest region as far east as Ohio and Kentucky. They are probably best explained as representing old swamp areas, which in a still more ancient time were ponds or lakes. All the prairies of the Chicago area are evidently of this type, being associated with former extensions of Lake Michigan. The climatic prairies are characteristic of the western prairie region, and are more puzzling than the others. Among the several explanations suggested, perhaps the most prominent is that which regards the absence of a natural forest on the western prairies as due to the prevailing dry winds. The extensive plains farther west develop the strong and dry winds that sweep over the prairies, and this brings extremes of heat and drought, in spite of the character of the soil. In such conditions a seedling tree could not establish itself. If it is protected through this tender period, it can maintain itself afterward. These prairies, therefore, represent a sort of broad beach between the western plains and the eastern prairies and forests.

The climax type of plant association in temperate regions is the *deciduous forest.* Such forests may be pure or mixed. A common type of pure forest is the beech forest, which is a dark forest, the wide-spreading branches of neighboring trees overlapping so as to form a dense shade (Fig. 237). In such a forest, therefore, there is little or no undergrowth. Another pure forest, which belongs to drier areas, is the oak forest, which is a light forest, permitting access of light for lower plants. In such a forest, therefore, there is usually more or less undergrowth. The typical American deciduous forest, however, is the mixed forest, made up of many varieties of trees, such as beech, oak, elm, walnut, hickory,

FIG. 237. — A beech forest in southern Indiana; a pure and dark forest.

maple, gum, etc. Deciduous forests may be roughly grouped also as upland and flood-plain (river bottom) forests, the former being less luxuriant and containing fewer types, the latter being the highest type of forest growth in its region.

The forests of the rainy tropics, called *rainy tropical forests*, may be regarded as the climax of the world's vegetation (Fig. 238), for the conditions favor constant plant

Fig. 238. — A tropical forest. — Photograph by Land near Xalapa, Mexico.

activity a the highest possible pressure. Such great forest growths are found within the region of the trade-winds, where there is heavy rainfall, great heat, and very rich soil, as in the East Indies, and along the Amazon and its tributaries. So abundant is the precipitation that the air is often saturated and the plants drip with the moisture. In a great mixed tropical forest there is no regular period for the development or fall of leaves, and hence there is no time of bare forests or of forests just putting out leaves. Leaves are continually being shed and formed, but the trees always appear in full

foliage. The density of growth is always remarkable, resulting in a gigantic jungle, with plants at every level, interlaced by great vines and covered by perching plants; in fact, all the space between the ground and the tree-tops seems to be packed with plants.

155. **Summary**. — Different areas support different kinds of plants, and plants naturally assembled on any area form a natural association. Each association of plants has its own habitat. The chief features of a habitat that determine what plants shall occupy it are available water, temperature, soil, exposure to light, prevailing winds, etc.

Certain kinds of plants dominate and give character to the association established upon a habitat. The other members of the association must adjust themselves to the dominant plants, and learn to live under whatever conditions the dominant plants permit. In any association of plants the plant population is in proportion to the number of kinds of plants included in the association. A single kind of plant cannot produce as many individuals on a given area as can several kinds of plants.

The most important fact about plant associations is their succession, which means that an association makes a habitat unfit for itself and more fit for some other association. The succession on any area ends in a climax association for that region, and in general the climax is some kind of forest association.

PART II

PLANTS IN CULTIVATION

NOTE TO TEACHERS

In addition to what has been said in the general preface concerning the purpose of Part II, the attention of the teacher should be called to a few practical suggestions.

Such a subject as plants in cultivation must include a much wider range of plants than those commonly recognized as producing "crops." It must include not only the products of agriculture, but also the plants that enter conspicuously into our experience, either as plants (cultivated flowers) or as plant products (lumber and fibers). This more extensive contact with the commercially important plants not only gives a more adequate conception of the uses of plants, but also makes it possible to supplement the relatively poor facilities for agricultural operations in connection with city schools, by the exceptional facilities of city schools to observe a wide range of plant products in the city markets.

It will be of very great service for the teacher to apply to the Agricultural Experiment Station of the state for material and for information. A great number of bulletins are published by the stations, dealing with the conspicuous crops of the state, and giving suggestions as to their cultivation. By means of these bulletins, a more intensive study of the state crops can be made than is suggested by the book, which cannot emphasize all the crops of all the states, but which suggests how to begin their study.

In addition to state bulletins and local information, some standard works of reference should be available, which can be consulted for fuller details than any text-book can give. A very useful work of this kind is Bailey's *Cyclopedia of American Horticulture* (4 vols.), which contains all the infor-

mation that could be needed in reference to the cultivation of plants, except in reference to the cereals. The cereals are likely to be well cared for by the station bulletins.

The teacher must remember that while much that this part contains and suggests will have to be given as information, there is a large opportunity to do practical work. This work may be of the most varied kinds, as growing plants in the schoolroom or school garden, assigning work in home gardens, inspecting crops in fields and market gardens, examining and learning to recognize the trees in common cultivation, especially those used for street-planting, visiting markets and inquiring as to the sources and seasons of the various fruits and vegetables, visiting florists and learning to recognize the common ornamental plants, looking over cultivated plants for indications of disease, etc. In short, the opportunity is ample for developing an experience of great practical value, which will extend further than merely the cultivation of plants, and will include the personal interests of every pupil.

CHAPTER I

INTRODUCTION

1. **The use of plants.** — In Part I a brief account of the structure of plants and of their principal activities is given. This forms the basis of the science of Botany and develops some knowledge of a very conspicuous part of nature. But there is another aspect of plants, which does not deal with them as a source of knowledge, but as things of great use. Comparatively few people are interested in knowing about plants, but every one is interested in using plants.

When one recalls the uses made of plants, he realizes that the human race is very dependent upon them. Of all the uses to which plants are put, however, the most conspicuous is their use as a source of food. In fact, even the meat we use is obtained from animals that feed upon plants; so that, directly or indirectly, all food is derived from plants. It is evident that this must be true, because, as was stated in Part I, green plants are the only living things that can manufacture food out of raw materials; that is, materials that are not food. It is upon this food manufacture that all plants and animals depend; the green plants use the food they manufacture for themselves, while plants that are not green (as mushrooms) and all animals depend upon the food that green plants manufacture in excess of their own need.

The most primitive men, of course, as they roamed about, obtained their plant food from wild plants. Even yet there is much "wild food" used, notably such berries as blackberries, raspberries, huckleberries, etc. An important stage in the progress of the human race was when men began to select certain of the wild plants for cultivation. The rais-

ing of crops checked the roaming of men, and they began to "settle down" and cultivate definite areas of land. In this way, tribes of wandering hunters became transformed gradually into groups of farmers. One of the most ancient occupations of men, therefore, was the cultivation of plants. When one considers the many thousands of kinds of plants, it is a surprise that only a few hundred have been selected for cultivation in the whole history of the human race. The reason is that the few selected have supplied the needs of the human race, but there is a rich, unworked mine in the thousands of plants that have not yet been brought into cultivation.

2. **Cultivated plants.** — The first plants cultivated seem to have been the cereals. The grains of certain wild grasses attracted attention as suitable for food and easy of cultivation, and thus the cultivation of wheat, oats, barley, and rye began. These grasses, apparently the first selected, have continued to be cultivated as exceedingly important food plants. Later, other grasses came into cultivation as food plants, notably rice and corn, and thus our most important cereals were assembled. A further addition to the list of cultivated grasses was made when the need for crops of hay as food for domesticated animals was developed. For this purpose, suitable meadow grasses were selected, but they have not been cultivated with the definiteness and care that have been given to the cereals. The reason for this has been that meadow grasses occur abundantly in nature, suitable both for grazing and for cutting; and in addition to this, plants of other groups have been found to be extremely valuable as forage plants (that is, suitable for stock), as clover and alfalfa.

3. **Agriculture and horticulture.** — The cultivation of the cereals and of the forage plants is the work of the farmer, and is included in the practice called *agriculture*. This word means "field-cultivation," and has come to include not merely the field-cultivation of food plants, but also the culti-

vation of domesticated animals. The work of the farmer, therefore, is plant and animal cultivation, and it is the most important work in the world on the side of our material needs, for upon the results of this work the human population is absolutely dependent.

In addition to field crops, which are generally referred to under the head of agriculture, and which are chiefly the cereals, there are the so-called garden crops, which include a great variety of plants. "Garden-cultivation" is *horticulture*, and it has come to include the cultivation of fruits, of vegetables, and of flowers and ornamental plants. In a broad sense, all cultivation of land for producing crops is agriculture, but it is often convenient to distinguish among the crops. For example, although the cultivation of flowers and ornamental plants is usually included under horticulture, it is often referred to as *floriculture*.

By whatever names the various kinds of culture may be called, the obvious fact is that ordinary plant culture deals with five large kinds of crops: (1) cereals, (2) forage plants, (3) vegetables, (4) fruits, and (5) flowers and ornamental plants. Attention has been called to the fact that very few plants have been selected for cultivation. It was natural for men to begin with a few plants when agriculture was just starting; but the descendants of these men have not added as many to the list as would be expected. The wild plants that might be selected from number nearly 150,000 kinds; while the plants cultivated in any extensive way for food hardly number 150 kinds. Either our ancestors were remarkably acute in selecting out all of the very useful plants, or their descendants have failed to take advantage of a wealth of opportunities all about them.

In the cultivation of plants, the two things to be considered are the plant and the soil.

4. **The plant.** — After the right kind of plant has been selected, one must know what that plant needs; not only

what plants in general need, but also what that particular kind of plant needs. It is also true that the needs of a plant do not always remain the same throughout its whole development. There are three distinct periods in the history of most cultivated plants which must be recognized. The first period includes *germination*, the starting of the plant, whether from a seed, a tuber, or a bulb. The second period includes *growth*, which means the development of a vigorous body. The third period includes *maturing*, which means the ripening of seeds and fruits, the proper development of flowers, etc. The demands of the plant are different at these different periods. In nature, plants have adjusted themselves to the changes of the seasons, so that in general the conditions at sowing time differ appropriately from the conditions at harvest time; and in general men leave their cultivated plants in these particulars to the chances of nature. But in proportion as the varying needs of these different periods are appreciated, men will be able often to help the plants to their best development.

5. **The soil.** — In addition to knowing the needs of the plant, the cultivator of plants must know the possibilities of the soil in reference to plants. We are coming to realize that soil is a very complex thing and that we do not know very much about it as yet. But men have used it so long in cultivating plants that they have learned some of the necessary things to do, although they may not be able to explain why they are necessary. That soil in general is adjusted for plant growth is evident because in nature it is clothed with vegetation. But we have learned that we cannot leave our cultivated plants to an unworked soil and get a respectable crop. We must know how to handle the soil so that it may be adjusted in the best possible way to the needs of plants. In order to adjust the soil we must know what it contributes to plants, where it gets the materials to contribute, how it presents the materials to the plant. If we know these

things and others like them, we may be able to be of decided help to the plant; and furthermore, we may be able to help the soil without abusing it, to use it without diminishing its usefulness.

It is obvious, therefore, that in the following pages we must consider the structure and rôle and manipulation of the soil so far as plants are concerned, as well as the needs of our cultivated plants and how to meet them.

CHAPTER II

WHAT PLANTS NEED

6. **General statement.** — Such plants as we cultivate may be thought of as living machines that manufacture food, that grow, and that finally store food. In general, it is on account of the stored food that they are cultivated. If the manufacture of food is to be carried on efficiently, there must be favorable conditions and available materials. It is necessary to discover what these are, and also whether we can be of assistance in supplying them.

What may be spoken of as the conspicuous conditions for successful plant work are oxygen, light, and heat. The practical question is, therefore, how can we assist plants in securing these conditions?

7. **Oxygen.** — In reference to the oxygen supply obtained from the air, it is evident that it is abundant for the parts above ground wherever plants are cultivated. But there are living and working parts of the plant imbedded in the soil, and most plants are started by seeds buried in the soil, and here the problem of a free oxygen supply calls for our help. If the spaces within the soil are filled with water, the air is excluded; if the soil is packed too firmly, the air cannot circulate; or if there is too much clay in the soil, the air is not free to move. All such conditions must be remedied if plants are to grow well. The water must be drained off; the soil must be loosened up; the impervious clay must be mixed with something that will give a looser texture to the soil. One of the most common blunders in planting seeds when artificial watering is employed is to use too much water, so that the seeds are in a " puddle " and the air is excluded.

8. **Light.** — When it is said that light is necessary for plant work, this does not mean that bright sunlight is necessary. Very ordinary light seems to be sufficient, and certain experiments indicate that very much less light than plants usually receive is not injurious. It is evident, therefore, that cultivated plants are not likely to lack light. It is not so much a question, however, of the total amount of light as of the presence of certain active rays of light that plants use in the manufacture of food. When light passes through smoke, its usefulness to plants is much diminished, and this becomes a serious problem in the neighborhood of factories, and in smoke-ridden towns and cities. When light has passed through foliage, the necessary active rays have disappeared, so that plants cannot grow completely shaded by other plants. This is recognized in a general way when the scarcity of low vegetation in a dense forest is noted; but even the densest forest lets some unscreened light through, and does not form so complete a shade as many a cultivated crop forms. It is a wise thing, therefore, to see to it that plants under cultivation are not densely shaded by other plants.

9. **Heat.** — The favorable condition of temperature varies for different plants and for the different periods of the same plant. In general, a lower temperature is more favorable for a seedling than for a maturing plant, and this fact is recognized in the spring sowing and summer harvesting of ordinary crops, as wheat. The variation in the temperature requirements of different seedlings also explains why some seeds are planted earlier in the season than others. The successful extension of crops into different latitudes has depended upon securing varieties with different temperature ranges. The results of passing beyond the best temperature range in either direction are soon obvious in a plant. If the temperature is too low, the plant grows very slowly; if it is too high, the plant becomes unusually tall and slender; and in both cases its lack of vigor is shown by the fact that it is unusually

subject to disease. In certain kinds of crops, these symptoms suggest some kind of protection against excessive cold or heat.

10. **Water.** — Water may be regarded not only as a necessary condition for plant work, but also as a material used in the manufacture of plant food. The active plant body is really saturated with water, and the living substance (protoplasm) cannot work effectively unless it contains an abundance of water. In addition to the water that puts a plant in working condition, a much smaller amount is used in the manufacture of carbohydrates (sugar and starch) by leaves. A saturated plant exposed to air means a continual evaporation from its free surfaces, and notably from its leaves. This loss must be made good by the continuous entrance of the water of the soil into the roots, so that there is a continual movement of water through a plant. When the loss of water exceeds the supply, the immediate effect on the plant is seen in its "wilting." It is this condition that all plant cultivation must guard against.

In the case of many field crops, there is no control of the water supply, and the farmer must take his chances that the rainfall will be adequate. But in gardens it is usually possible to supplement a failing water supply, and in dry regions where irrigation is used the water supply is under control. In all cases where water is supplied in some way by the cultivator, it is necessary to learn the needs of the crop. Generally too much water is supplied, which injures both the plant and the soil. It should be recognized also that the amount of water required varies with the period of the plant; for example, more water is needed during the growth of the plant than during either seed-germination or ripening. The problem is not merely to induce plants to grow by just keeping them from wilting, but to enable them to grow vigorously. Too little water during the growing period results in smaller leaves and less work; while a supply of water that favors

vigorous growth, if continued too long, will delay ripening. No definite rules for watering can be given, for it is only experience in observing the condition of plants that can suggest the amount of water necessary.

In determining what crops can be grown to the greatest advantage on a given area, the supply of water must be taken into account. For example, where there are drier and wetter areas, wheat would be appropriate for the drier ground and meadow grass for the wetter, and so for each crop. The ability to select the most suitable plant for a given area is one of the first things a cultivator of plants must acquire, unless the water supply is under control.

In considering the other materials needed by the plant, it will not be necessary to include all that have been found to be used by plants, but only those that have proved to be the most important.

11. **Carbon dioxide.** — Of course carbon dioxide must be ranked with water as of first importance, because these two materials are used in the manufacture of carbohydrate food, upon which also depends the manufacture of other foods. Since carbon dioxide enters the plant from the air, its supply is usually sufficient, and in any event there is nothing to do in the way of regulating the supply.

12. **Nitrogen.** — The other materials needed by the plant are obtained from the soil, and with these the practice of agriculture has very much to do. Chief among these materials are the compounds of nitrogen. Although nitrogen forms a very large part of the air, it cannot be used by plants in its free condition, but must be obtained from its compounds. Of all the compounds of nitrogen, it appears that the nitrates are most used by plants. It is evident, therefore, that nitrates must exist in the soil if plants are to be grown; and that if they become insufficient in amount, they must be restored in some way. As in the case of other things that plants need, the nitrates may be not only insuffi-

cient in amount, but they may be excessive in amount, so that too much as well as too little is injurious to the crop. The plants show the symptoms of both these troubles, lack of nitrates resulting in starved-looking plants, and an excess of nitrates resulting in weedy-looking plants and delayed ripening. For example, with an excess of nitrates, cereals " run to straw " and ripen poorly. Of course, if rank growth rather than grain or fruit is desired, as in the case of cabbages, a larger amount of nitrates is helpful. This will serve to illustrate how the use of nitrates will depend upon the kind of plant, the age of the plant, and the product desired. This means that the successful cultivator of plants must develop an experience in the observation of his plants that will enable him to recognize their symptoms.

In connection with the problem of nitrogen supply, it is important to know that leguminous plants have developed an unusual method of securing nitrogen. These plants include such crops as clover and alfalfa. In these cases, therefore, the problem of nitrogen supply is very different from that in non-leguminous plants. Such plants as clover and alfalfa can draw upon the free nitrogen of the air, as it circulates in the soil, by means of their association with certain bacteria of the soil which have the power of " fixing " free nitrogen in its compounds. Leguminous plants, therefore, are very useful in increasing the amount of nitrates in the soil; while non-leguminous plants, if removed as crops, diminish the amount of nitrates. This fact explains the significance of a very common form of " rotation of crops," for it is obvious that the supply of nitrates in a soil may be kept sufficient by alternating crops of leguminous and non-leguminous plants. The clovers and alfalfa are used extensively in this way.

13. **Phosphorus.** — Another important group of substances needed by plants and supplied by the soil are phosphates, from which the growing plants obtain such phosphorus as

they need. One of the remarkable effects of phosphates has been shown to be a greater ability to form roots, so that in soils, as clays, in which roots do not develop readily, phosphates are of great use. Phosphates are also said to hasten the ripening processes. It should be recognized, however, that fluctuations in the supply of phosphates do not show such important results in the plant as fluctuations in the supply of nitrates. In fact, plants show decided symptoms of nitrogen starvation, but there are no recognizable symptoms of phosphorus starvation. One of the questions under discussion is as to the natural supply of phosphates, some maintaining that the phosphates are disappearing from the soil in an alarming way, and others maintaining that the supply is sufficient for an indefinite time.

14. **Other soil salts.** — Numerous other salts, as the compounds in the soil are called, are needed by plants in one way or another, as compounds of sulphur, potassium, calcium, magnesium, iron, etc. What these substances enable the plant to do is known in some cases, but in others the particular use has not been discovered. But they are all constituents of the soil, and have to be reckoned with.

15. **Toxic substances.** — It is not only necessary to determine whether a soil contains the substances that plants need, but also whether it contains substances injurious to the plants we wish to cultivate. Such substances are spoken of in a general way as toxic substances. For example, a soil may contain too much acid or too much alkali, and such a soil must be treated accordingly, that it may become more neutral. Compounds of metals getting into the water supply in the waste products drained away from industrial establishments working on metals may be very injurious to cultivated plants. Gases of various kinds diffused through the air from manufacturing establishments may be very destructive to plants, or at least prevent vigorous growth.

16. **Limiting factors.** — It is evident that in cultivating plants we are not dealing with one condition or one substance, but with a complex of conditions and substances. The various conditions and substances may be spoken of as factors that have to do with successful plant growth. We have discussed six important factors and have indicated several more. It is a very common mistake to suppose that if some one factor is supplied, plants will do well. For example, some will say that a proper water supply will insure good plants; others will claim that a supply of nitrates is all that is necessary for plants to do well; still others are just as strenuous in reference to phosphates as the only cure for feebleness in plants. In this way a great number of so-called "fertilizers" have been devised, each claiming to supply all plants whatever they need. It must be evident, when it is appreciated that numerous factors in combination are affecting the plant, that any factor or even several factors may be favorable, and yet the plant cannot do well if any one necessary factor is unfavorable. In other words, a plant cannot do any better than the most unfavorable factor permits, and such a factor is called a limiting factor. For example, the necessary nitrates or phosphates may be supplied, but if the water supply is too scanty or too abundant, the water is a limiting factor, and the nitrates or phosphates cease to be serviceable. In another case the water supply and the phosphates may be just right, but if the supply of nitrates is not right, then the nitrates form the limiting factor and impede the plant in spite of its favorable water and phosphate supply. Any one of a half dozen or more factors, therefore, may be a limiting factor, and it is the limiting factor that determines the success of a plant. It is like a group of men walking; the group as a whole advances no more rapidly than the slowest walker. In other words, the slowest walker is the limiting factor.

When plants are not doing well, therefore, the course to

pursue is not to apply some treatment that is claimed to be a cure-all, but to discover, if possible, the limiting factor which is holding back the usefulness of the numerous factors that are all right. A plant that is not doing its best is like a train moving with brakes set; and the thing to discover is the factor that is acting as a brake.

The increased success of agriculture and of horticulture will depend largely upon the development of an ability to recognize limiting factors. The difference between the old agriculture and the new will be the difference between the method of the old medical practitioner, with his calomel and quinine for every ailment, and the method of the modern practitioner, with his developed powers of diagnosis and his great variety of prescriptions. It is very important for the cultivator of plants, at the very outset of his training, to possess the idea of limiting factors.

CHAPTER III

WHAT THE SOIL SUPPLIES

17. Chemistry of the soil. — The soil is a mixture of many substances that have come from various sources. In the first place, its original material and relatively permanent part consists of material derived from rocks in various ways, such as particles of sand, clay, etc. If during its history it was submerged in sea water or fresh water, it became mixed with shells of water animals, which contributed calcium salts (carbonates and phosphates). When it began to be covered with vegetation and the plants contributed their bodies to the mixture, there was a slow accumulation of this organic material (*humus*) which gave a dark color to the soil mixture. To all of these substances the water of the soil must be added as of great importance, containing in dilute solution the substances of the soil that are soluble.

The differences among soils are brought about by the various proportions in which these substances occur in the soil mixture, and it is evident that the combinations are numerous. Soils are spoken of as sandy soils, clay soils, lime (calcareous) soils, alkali soils, acid soils, humus soils, etc., because they are rich in sand, clay, lime, salts, acids, humus, etc. Humus soils, rich in organic material, may be too acid for plants of ordinary cultivation because there is not enough lime to neutralize the acids from decomposition; but when there is sufficient lime, the humus is rendered neutral and is very favorable for plants.

The effects of these numerous substances upon one another are intricate and poorly understood, but enough is known to assure us that chemical changes are always in progress,

and that the soil, in this respect, may be regarded as a chemical laboratory where work is going on continuously.

18. **Physics of the soil.** — Not only is the chemistry of the soil necessary to consider, but the physical properties are also very important. This is a subject of great difficulty on account of the complex mixture. The physical properties of a mass of pure sand or of pure clay may be discovered with comparative ease, but when many substances, with different physical properties, are mixed together, the resulting physical properties of the mixture as a whole form a far more difficult problem. From this point of view, the soil may be regarded also as a physical laboratory, which is but dimly understood.

A few examples will illustrate what is meant by physical properties. One of the most important physical properties of soil is its relation to water. In fact, the capacity of soils to receive water and to retain it in an available condition for plants is the most obvious physical feature that cultivation of the soil seeks to control. The clay constituent of a soil, which is a very important one, may be taken as an illustration of the relation of one kind of soil material to the water supply. A certain amount of clay interferes with the free movement of water, and therefore prevents it from draining away too rapidly; it thus increases the retentive power of the soil. But an excessive amount of clay interferes too much with the movement of water and results in a water-soaked soil which is very injurious to plants on account of the exclusion of air. The converse is true in reference to sand. A certain amount of sand makes the soil open to the movement of water, thus increasing its receptive power; but an excessive amount of sand makes the soil too open, so that the water drains away rapidly and the soil becomes dry.

The lime constituents of the soil are very important both chemically and physically. Soils with insufficient lime are spoken of in general as "sour." Wherever decomposition of organic matter is going on, as is true of all good soils, there

is a liberation of acids, and if these accumulate, the soil becomes literally sour, a condition which the presence of lime corrects by neutralizing the acids. But lime is also of great value in clay soils in a physical way, by mixing with the clay and making the soil of better texture for the handling of water.

The humus (organic material) of the soil greatly increases its water-holding capacity. In fact, a forest soil, in general the best example of a humus soil, has the physical properties of a sponge in receiving and retaining water.

It becomes evident that in this single matter of water relations the proper balance among the various soil constituents is of great importance, and that this balance may be secured in a variety of ways. It should not be forgotten that the physical properties of the soil mixture in reference to water represent only one phase of the physical properties of soil.

19. **Life of the soil.** — The soil is not only a chemical laboratory and a physical laboratory, but it is also a biological laboratory. This means chiefly that it contains multitudes of the exceedingly minute plants called bacteria. The bacteria of the soil have come to be recognized as the most important agents for putting the soil in proper condition for such plants as we cultivate. Bacteria are active in all decompositions of organic material, which is thus reduced to substances that the plants can use. They are active also in many other useful changes of soil material. Conspicuous among their activities, however, is their relation to the nitrogen supply of the soil. Certain bacteria, unlike other plants, can use the free nitrogen of the air, and in this use the nitrogen enters into compounds that cultivated plants can use. This is spoken of as the " fixation " of nitrogen, which simply means taking free nitrogen and putting it into compounds. It is evident, since plants must always have a nitrogen supply from the soil, that this work of the nitrogen-fixing bacteria

is of the first importance. In removing crops the nitrogen compounds obtained by the plants from the soil are removed also, and if there were no way of restoring these compounds, the soil would sooner or later become so impoverished in them that it could not produce a good crop; in other words, it would result in a nitrogen famine.

Since the nitrogen-fixing bacteria are continually adding nitrogen compounds to the soil, the loss is represented by the difference between what the crops remove and what the bacteria add. This difference varies with the crop and with the soil, but in most cases there is a real loss, so that continuous cropping reduces the amount of nitrogen compounds to the danger point. If a field has become reduced to the point of a nitrogen famine, it may be restored to usefulness by " resting " for a time until the bacteria have restored the nitrogen compounds. This resting of a field, that is, not working it for a crop, is called letting a field lie fallow.

The restoration of nitrogen compounds in this way, however, is usually too slow a process for our purpose. A much more rapid way is by means of a " rotation of crops." It is found that soil is kept in much better condition as to nitrogen if the same crop is not grown continuously upon it. Crops vary as to their wastefulness of nitrogen, so that if a crop that removes a minimum amount of the nitrogen compounds alternates with a crop that removes a maximum amount of these compounds, a nitrogen balance may be maintained. By far the most effective rotation is secured by using leguminous plants as the alternating crop, notably the clovers and alfalfa, for these plants add nitrogen compounds to the soil. This peculiar property of leguminous plants is due to the fact that their roots become intimately associated with nitrogen-fixing bacteria which inhabit tubercles (little tubers) that form on the roots, and in these tubercles there is an accumulation of nitrogen compounds not obtained from the nitrogen compounds of the soil, but produced by the bacteria in using

the free nitrogen of the air. Such plants, therefore, not only do not draw upon the nitrogen supply of the soil, but they are the means of adding to it.

20. **The soil complex.** — The above paragraphs give only a glimpse of the complexity of the soil, with its chemical constituents, its physical properties, and its active bacterial life. It is a great complex in which changes are always taking place, and which can be thrown out of balance in a number of ways. Left to itself and to natural vegetation, it becomes better for plants with each succeeding year; but interfered with by man, who rarely appreciates what he is doing, it frequently gets into bad condition. This is notably true when attempts are made to remedy unknown troubles by "fertilizing" with unknown substances, especially with the so-called "chemical fertilizers," which are as dangerous to the soil in the hands of inexperienced people as are strong medicines in the hands of the untrained. While destroying the chemical or physical equilibrium of a properly balanced soil is bad enough, any interference with the bacterial life of the soil is worse. These statements merely serve to emphasize the fact that any efficient manipulation of the soil, especially in adding materials to it, requires experience and considerable knowledge.

21. **Tillage.** — The preceding paragraphs have outlined in a general way what the soil supplies to plants we cultivate. It is well known, however, that all the appropriate materials may be present, and yet the soil must be "worked" for planting seeds and also to help the growing plants. This "working" of the soil is called *tillage*, and its purpose is to put the soil into the best possible physical condition. Tillage of the soil is the first and principal thing, and often the only necessary thing. If any "fertilizers" are to be added, this is a matter of secondary importance. In fact, there is much experience to show that proper tillage reduces and often eliminates the need for fertilizers. Of course proper tillage

is laborious, and fertilizers are often used as short cuts to save labor.

The breaking up of the soil for planting seeds is known to every one, but its purpose is not so widely understood. Many suppose that it is only a way of getting seeds into the ground, but that is the least important of its purposes. Its real purpose is to pulverize the soil, because finely pulverized soil is in the best physical condition for plants. In the first place, it secures a good circulation of air, which we have learned is essential for the best plant growth. In the second place, it enables the soil to hold a much larger amount of moisture. Strange as it may seem at first thought, the smaller the soil particles and the closer together they are, the more water will the soil hold. This is explained by the fact that the amount of water held by the particles is approximately in proportion to the surface they present, and of course there is much more surface presented by very numerous small particles in a given space than by less numerous large particles. The capacity of a soil for water, therefore, is in proportion to the minuteness of its particles. This combination of small particles and free circulation of air is an ideal combination for productive soil. Of course, pulverizing the soil also improves its drainage, and so permits unimpeded circulation of air.

The ideal physical condition of the soil is attained in the potting of plants, in which the soil is pulverized and screened, but this degree of tillage is not practicable when large areas are concerned. And still it shows that the more persistent and painstaking the tillage, the better the results in crops.

After the soil is well tilled, and the seeds are sown, the work of tillage is not at an end. The physical conditions that favor germinating seeds also favor growing plants; therefore the soil must be kept in good physical condition. An additional advantage of tillage to growing plants must be mentioned, and that is the conservation of moisture. Water not only

drains away from the soil, retained more or less by a finely pulverized soil, but it also evaporates from the surface. If the surface becomes caked, it must be broken up and pulverized so that the soil can get a new grip on the water, or the loss may be serious. Tillage, therefore, checks evaporation as well as loss by drainage. In fact, in dry farming it has been found that a shallow pulverized layer of soil acts like a " mulch " or a blanket in checking evaporation. Of course it is common to use an artificial " mulch " for the same purpose, such as a layer of ashes or sawdust or leaves; but shallow tillage provides a natural mulch.

22. **Capillary movement of water.** — It must not be thought that the only water available for plants is that which is held by the soil particles with which their roots come in contact. A most important fact is the capillarity of the soil. This means that when films of water held by the soil particles become thinner because some of the water has entered the roots, there is a rearrangement of the water in all the neighboring films. Water is always pulled away from a thicker film toward a thinner one, and this starts a movement of water from every direction towards the thinner films. Therefore, as water is lost from the soil by evaporation or by passing into root systems, there is a movement of water from the deeper parts of the soil. This is the so-called capillary movement of water, which is in the main an ascending movement. The available water for plants, therefore, is all the water in the neighborhood that is free to move through the soil. If the soil is in proper condition, this capillary movement extends to the water-table, which means the level where the ground begins to be saturated with water, usually because it is held by some material through which it cannot pass. This impervious material may be clay or rock. For this reason, not only is the soil in which the plants are rooted to be considered, but also the soil beneath, which is called the *subsoil*. For example, it is of great advantage to an open

sandy soil to rest upon a subsoil of clay, which holds a body of water within reach of the soil above. Without such a subsoil a sandy soil would be in danger of becoming too dry.

23. **Movement of soil salts.** — It is a very common mistake to suppose that the only soil salts available for plants are those with which the roots come in contact. For this reason, the different useful salts occurring in what is called "plough depth" of soil (6 to 9 inches) have been estimated, and the conclusion reached that when this amount of any necessary salt has been used up, the soil will be impoverished. What has been said concerning the capillary movement of water through the soil should correct this impression. The moving water contains the useful salts in solution, and therefore the salts are also moving towards the surface continually. It must be remembered that this movement is not only towards the points where the water and salts are entering the plants, but also towards the general surface from which the water is being evaporated. Quite apart from the use of salts by plants, therefore, they are continually moving towards the surface in solution and being deposited in the surface layers by the evaporation of the water.

This means that the salt available for plants is not only that which happens to be within the surface soil at a given time, but also all that is within reach of the water movement. This usually multiplies many times the amount in the surface soil, for the movement of water may extend to a great depth, and when it reaches the underlying rocks, the supply of certain salts may be indefinite.

24. **Soil analysis.** — There is a general impression that if a sample of soil be sent to a chemist to analyze, he can discover what it lacks and prescribe a suitable fertilizer. This kind of work is sometimes provided for upon an extensive scale. If the statements of the preceding paragraphs are true, it is evident that no such chemical analysis can tell what the soil of any farm needs. In the first place, the appropriate

materials are found in all soils upon which natural vegetation can grow. Soil is a variable mixture, and there is no fixed standard that determines the best mixture. In the second place, the immediate need of any soil is to be put in proper physical condition, and what is necessary to accomplish this can be told only by an examination of the area; it certainly cannot be told from a sample.

CHAPTER IV

SEEDS

25. **Seed structure.** — It will be well to recall just what a seed is and what it needs for germination. It is made up of three things that must be considered: (1) the hard covering (*testa*), (2) the young plant (*embryo*), and (3) the food supply (Fig. 1).

Testa. — Seeds differ in the hardness and thickness of the covering, and also in its permeability. Two things must pass through the seed coat before germination can begin, namely water and air (it is the oxygen of the air that is needed). Some seed coats are impervious to water, others to air, and others to both, and in nature they may lie in the soil for a long time before germination begins, awaiting changes in the testa, through decay or otherwise, that will permit the entrance of water or oxygen or both. For example, the testa of the seeds of lettuce is so impervious that the seeds are often stored for two or three years before being sold for planting, and throughout this period the germinating power is probably diminishing. On the other hand, peas and beans and corn germinate with great promptness. Mechanical means are being devised to remove the obstruction

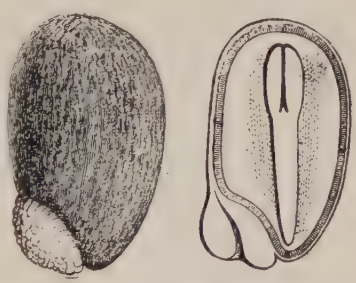


FIG. 1. — Seed of a violet: the right figure shows the hard seed coat (testa); the left figure is a section, showing the embryo surrounded by the food supply (endosperm), which in turn is surrounded by the testa. — After BAILLON.

to water and oxygen offered by the testa, and in the case of many seeds this will make a great difference in the promptness of germination.

Embryo. — The young plant enclosed in the seed, often called "the germ," is the structure that is to work and grow and escape from the testa. The living substance (protoplasm) of the embryo is in a dormant stage, which means that it is inactive; and it needs the water to put it in a proper condition for activity. As a general rule, the longer dormancy is continued, the less active the embryo is when aroused. The germinating power of a seed is called its *viability*, and viability diminishes as dormancy is prolonged.

This is not true for all seeds, for in certain cases changes are necessary in the embryo itself during dormancy before germination can begin. In these cases, therefore, viability increases as long as these changes in the embryo are occurring, but after the embryo has "ripened," the viability diminishes as germination is postponed.

Fig. 2. — Section of a grain of corn, showing the endosperm at one side of the embryo: fuller explanation in text on p. 349. — After Frank.

It is evident that the testa and the embryo of the plants we cultivate must be better understood before we can secure in every case prompt germination at the time of greatest viability.

Food supply. — In many seeds, as in the cereals, the food supply is packed around the embryo (Fig. 1), or at one side of it, as in corn (Fig. 2), forming a distinct region of the seed, called the *endosperm*. In other seeds, as peas and beans, the endosperm has been used up by the growing embryo, and the food substances have been redeposited in the seed-leaves (cotyledons) of the embryo, which become large and fleshy. In this latter case the embryo occupies all the space within the testa

(Fig. 3). It is upon this food material, whether stored in the endosperm or in the embryo, that the young plant must live until it establishes soil connections and exposes green leaves to the light and air. It is this period of dependence upon stored food that is called germination.

26. **Seed selection.** — The proper handling of seeds is no less important than the proper tilling of the soil. The character of seeds must be investigated before planting, for the character of the crop will depend upon a proper seed selection.

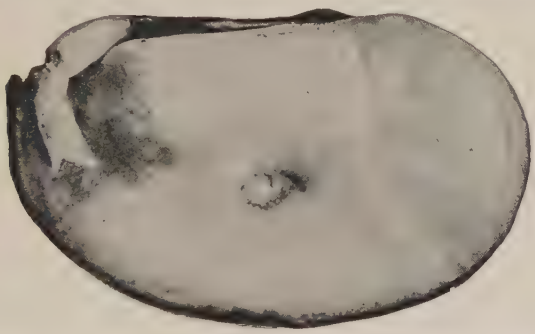


FIG. 3. — Section of bean, showing the embryo (chiefly the fleshy cotyledons) filling all the space within the testa.

Not very many years ago it was thought that any kind of seed is good enough to plant, and so in the case of cereals the best seeds were used for food, and the poorer seeds were saved for planting. In the case of plants whose seeds are not used for food, no attention was paid to the character of the plant whose seeds were used for planting.

It is now recognized, however, that seed selection is of the very first importance. A seed produces a plant that very closely resembles the parent plant, and if the parent plant is a poor specimen and has produced poor seed, its progeny cannot be expected to do any better. So important is seed selection, therefore, that it has developed a great industry, and the business of seed firms is to select seed, to improve it

as much as possible, and to multiply it in sufficient quantity to supply all who need it. In this way, those who wish seeds can get good ones to start with from reliable seed firms, but they should be able to select seeds from their own crops for subsequent crops.

In doing so, they must select a few plants that seem to be most desirable. Of course the standard of selection may vary; selection may be made for some quality, for yield, for appearance, etc.; but whatever it is, the plants selected must be those that come nearest to this standard. The seeds from these selected plants must be saved for sowing, and the next crop is likely to be a little better than the former one. If this careful selection is continued through a series of seasons, the successive crops will maintain their desired character and will probably improve.

In the case of corn, it has been found that after the selection of good plants, the most desirable ears must be selected. Of course this selection means the best ears from the best plants. This ear-by-ear selection in the case of corn is based upon the fact that all the grains of an ear of corn are remarkably uniform in character. This selection of seed corn, and its importance in the resulting crop, is being emphasized by the formation of "corn clubs" for boys in agricultural communities, and by contests between clubs. The United States Department of Agriculture is so much interested in such clubs that it issues bulletins for them and their contests, and has a specialist in charge of club work. These bulletins may be obtained for the asking.

27. **Seed-germination.** — After seeds have been selected from desirable parent plants, the question of their germinating power (viability) is an important one. In general, this germinating power is greatest in the next season after the seed is produced, which of course is the usual period in nature between seed-production and seed-germination. This implies that in general the germinating power of a seed diminishes

as it becomes older, until finally it cannot be made to germinate. This is a good general rule, but like all rules it has its exceptions. Failure to germinate at all plainly indicates poor seed; but unusually slow germination or feeble seedlings indicate declining power and relatively poor seed. Seeds may "sprout," that is, the enclosed plantlet may break the seed coat and begin to emerge (Fig. 5), but sprouting is not a complete test, for there may not be power enough to carry the germination to its completion, that is, until the young plant has established itself in the soil and has spread out its first leaves. It is important, therefore, to test the germinating power of samples taken from any lot of seeds obtained for planting.

The germinating power of seeds is tested in a variety of ways, sometimes with great exactness, requiring considerable apparatus to control the conditions; at other times with varying degrees of exactness, down to germination between two sheets of moist blotting paper. Since germination experiments can be conducted by any student, and with little or no apparatus, and since they are so fundamental in the cultivation of plants, as many experiments should be performed as the time will permit. In this case some of the simpler methods may be used. A very effective seed-germinator for class use is constructed as follows (Fig. 4): the bottom of a flat tin basin (like a milk pan), painted outside and inside to prevent rusting, is covered with water, and in it is placed the saucer of a small flower pot. In the bottom of the saucer a layer of moist blotting paper is placed; on it are laid the seeds to be germinated; and on the seeds another layer of blotting paper is placed. A pane of glass is used as a cover for the pan, and the apparatus is complete.

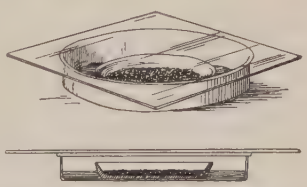


Fig. 4. — A simple seed-germinator explained in the text. — After Bailey.

It will be necessary to leave the pan partly open now and then to allow gas exchanges. The principles of this simple piece of apparatus may be used with a variety of details; as, for example, the substitution of two soup plates, one used as a cover, for the tin pan and the pane of glass (Fig. 4*a*). Of course the most complete test of the germinating power of seeds is obtained by planting in soil in conditions they must meet when sown for a crop. It should be known that seeds usually germinate much better in the ordinary germination tests than they do when actually put in the ground out of doors, so that one must not expect that the actual germination will equal the experimental germination.

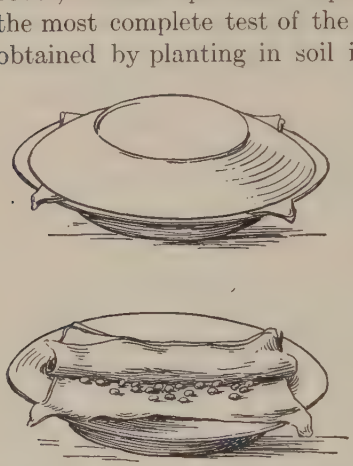
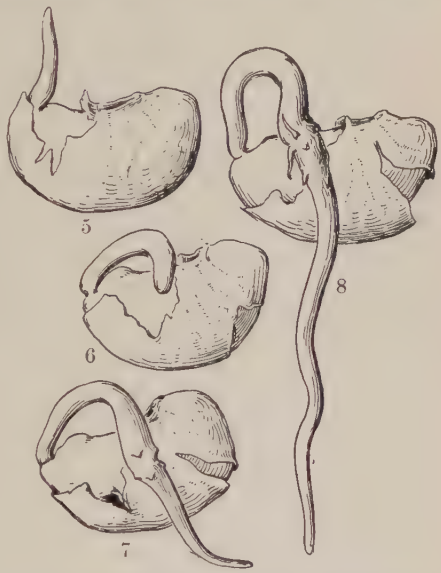


FIG. 4*a*. — A seed-germinator constructed by using home utensils, as soup plates or basins: in the upper figure the germinator is closed; in the lower figure it is open, showing the sheets of moist blotting paper (kept moist by water in the plate) between which the seeds are placed. — After WESTGATE.

The length of time necessary for germination varies widely with different seeds, and these periods should be learned for plants that one cultivates. As a rule, the period of germination is somewhat longer in soil than in the ordinary testing experiments in artificial conditions. As has been stated, some seeds have such a hard and bony covering that germination may be very much delayed, and in nature such seeds may lie for a season or two or even many seasons before germination occurs. It is evident that any treatment of seeds that will hasten germination is of advantage, but many suggested treatments have been disapproved for most seeds, as soaking in water or in certain chemicals before planting. It has been found, however, that any mechanical method of

thinning or puncturing or breaking the hard seed coat, without injuring the young plant (embryo), usually secures prompt germination. The whole subject of delayed germination is under investigation, and it is evident that it is a practical question of great importance. Experiments with different seeds should be performed to discover the ordinary variations in the germinating period.

The germination of beans, which is rapid, may be used as a preliminary experiment. Figs. 5–9 show some of the stages. In Fig. 5, the tip of the hypocotyl has broken through the testa; in other words, the bean has "sprouted." In Fig. 6, the hypocotyl is curving towards the earth; in Fig. 7, it has elongated considerably; in Fig. 8, it has penetrated the earth and put out rootlets, developing a sharp arch. In Fig. 9, the root system has gripped the soil, the cotyledons have been pulled out of the testa, the arch has straightened, the young stem bud (*plumule*) is seen between the cotyledons, and the seedling has established itself for independent work.



FIGS. 5–8.—A germinating bean: explained in the text.

28. **Depth of planting.** — There is no definite depth at which seeds should be planted, for it varies with the conditions. The thing to remember is that seeds should have continuous moisture in a well-tilled soil. When seeds are

FIG. 9. — A seedling bean just as germination has been completed: explained in the text.

planted in soil in pots or boxes, where the water supply is controlled, they may be more shallow than if planted in the open, where the surface soil is in danger of becoming too dry. It is well to plant seeds as shallow as possible, consistent with a moist soil. Attention has been called to the fact that a moist soil does not mean one saturated with water, which is a common mistake made in planting seeds, called very properly "puddling" seeds. The danger involved in preventing a free circulation of air by filling the soil spaces with water has been mentioned. Of course the soil is saturated with water after an abundant rain, but if there is proper drainage, this is a very temporary blockade to the air. The advantage of the rain, of course, is that in passing through the finely divided soil the water thickens the water films held about the soil particles, and adds to the supply of water in the deeper region of the soil which can be drawn upon by the capillary movement.

29. **Seed boxes.** — In cultivating many garden plants (including, of course, flowers and ornamental plants) it is often of great advantage to germinate the seeds in shallow boxes containing soil, such seed boxes as professional

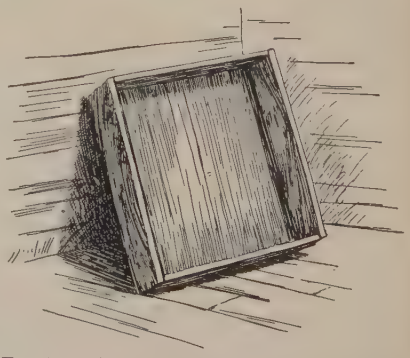


FIG. 10. — A gardener's seed box for germinating seeds. — After BAILEY.

gardeners use (Fig. 10). In this case such germinating conditions as water and temperature can be controlled, so that the accidents of dryness and chill can be avoided at a very critical period. In this way germination is also more prompt than in the ordinary conditions out of doors, so that the young plants get started earlier. Another very important advantage is that the poor seedlings can be discovered and discarded, and only the vigorous, promising ones used in the permanent bed. This enables one to supplement seed selection by seedling selection, and the result is a good, clean, uniform crop.

The transplanting of the selected seedlings into properly prepared permanent beds is a simple performance which a little practice will make rapid and effective. The only suggestion needed is that the rootlets of the seedling should be disturbed in their soil connections as little as possible, and so with each seedling there should also be transplanted a little of the soil in which its root is imbedded. Of course seedlings may be pulled out of the soil and transplanted, but time is lost in their recovery from this rough treatment.

CHAPTER V

OTHER METHODS OF PROPAGATION

30. **Vegetative propagation.** — Plants can be propagated in other ways than by their seeds, and advantage is often taken of this fact. Among the advantages secured are a more rapid production of plants and a greater certainty that the plants will come true to type. The greater rapidity of production is secured by eliminating the germination and seedling stages, and starting with considerable maturity. In the case of plants of long periods, as shrubs and trees, this shortening of the period between the start and the crop is of great importance. Greater certainty as to the character of the plants produced arises from the fact that a seed has come from the act of fertilization, and this usually involves the characters of two parents; while the other methods of propagation involve the vegetative continuance of one individual. For example, no one thinks of raising potatoes from seeds to secure a crop. By using the tubers (thickened underground stems), new potato plants are secured much more speedily, and the new tubers are like the parent tuber. In addition to seed propagation, therefore, it is necessary to consider vegetative propagation. The principal kinds of vegetative propagation may be included under three heads: (1) cuttings, (2) layering, (3) grafting.

31. **Cuttings.** — By this is meant that cuttings or "slips," usually of the stem, can be used to produce new plants. A stem is made up of *nodes* (joints) and *internodes* (the parts of the stem between the nodes). The nodes have the power to produce lateral members, which ordinarily are leaves and branches; but when nodes are put in the proper soil condi-

tions, they can produce roots, also. Therefore, if a node puts out a branch, which is merely a new stem, and at the same time strikes root, a new and independent plant is started. It is evident, therefore, that propagation by cuttings is secured by planting nodes, and that a good vigorous node should be able to produce a new plant, which is a vegetative continuation of the old plant. Not only are cuttings of stems used for propagation, but also in some cases cuttings of roots and leaves.

It must be understood that propagation by cuttings is not used with all cultivated plants, and it is not known how many of them could be propagated in this way. Some of the more important plants propagated by cuttings and the general method of procedure may be indicated by a few illustrations. The details differ more or less for each kind of plant propagated in this way, and facility in this work can only be secured by learning what is necessary in each case and by practice.

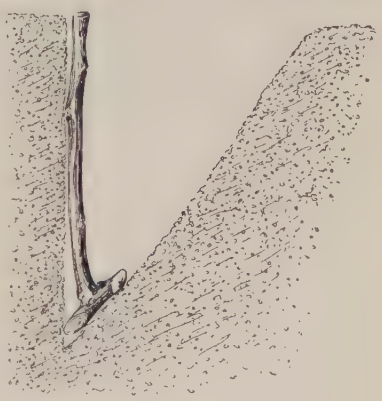


Fig. 11. — A cutting in position in a trench. — After Bailey.

A conspicuous illustration of the use of stem cuttings is in the propagation of grapes. In this case the stems of the current year are secured late in the season, before severe cold, and either stored or made into cuttings at once. When either stems or cuttings are stored, they must be kept in a cool place and prevented from drying out by some such covering as fresh moss or earth. The usual practice in making the cuttings is to include at least two nodes (indicated by buds), the cutting thus being six inches or more long, the upper cut

being just above the upper bud. In the spring, the cuttings are planted "right end up," in well-tilled soil, so that the upper bud is at the surface. The cuttings are not planted by being thrust into the soil, but are placed about a foot apart in trenches and covered up (Fig. 11). If the cuttings and the soil and the planting are all what they should be, many of the cuttings will establish plants during a single season, which are then ready for transplanting into a permanent position.

These details will vary with different plants, largely dependent on the use of young wood or mature wood for cuttings, or on the use of short or long cuttings. In the grape cuttings just described, the cuttings are long and contain mature wood.

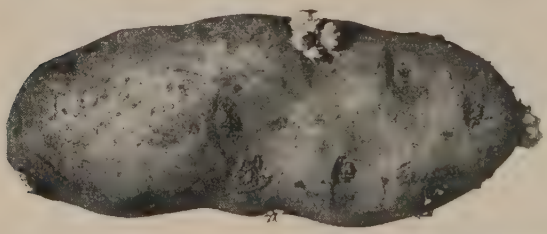


Fig. 12. — Potato tuber, showing the "eyes" which indicate nodes, and also some young branches ("sprouts") started.

The best illustration of the use of cuttings of underground stems is in the propagation of potatoes. The potato tubers are thickened underground stems, and their nodes have all the powers of those of aërial stems (Fig. 12). The position of these nodes is indicated by the so-called "eyes," which are young buds in the axils of more or less evident scales (which in this case might be called "eyebrows"). The cultivation of potatoes will be described later, but in this connection the preparation and planting of the cuttings will be indicated. The tuber is cut in such a way that each piece to be used for planting contains one or two eyes; and at the same time each piece must contain as much food material as possible. The bud (eye) is a young shoot, capable of developing a stem with its leaves, and the node in the proper soil conditions can also put out roots. This means the organization of a new

plant, but until it is established and independent, it must depend upon the food stored up in the old tuber. It is evident, therefore, that the node, with its bud, must be in connection with as much of the old tuber as possible, if the new plants are to start rapidly and vigorously. The depth of planting is different for early and late potatoes, being two or three inches in the former case, and nearly twice as deep in the latter. The character of the soil and the nature of the cultivation for this very important crop will be considered in another connection.

The same general principles, applied with different details, appear in propagating by root-cuttings, as in the case of raspberries, sweet potatoes, etc., or by leaf-cuttings, as in the case of begonias.

Fig. 13. — Layering a plant, as a rose or raspberry. — After Bailey.

31*a*. **Layering.**—Propagation by layering is really only a modification of propagation by cuttings, the difference being that nodes of the stem are made to strike root before they are separated from the parent plant. In case plants can be propagated readily by cuttings, the less convenient method of layering is not used. An outline of the method is as follows: In such plants as certain of the roses and raspberries, a long and flexible young branch is bent down to the ground, fastened in place, and the end carried up and held in an upright position above ground (Fig. 13). The bent portion

is covered with good soil, which puts some nodes in a favorable condition for striking root. It facilitates the growth of roots if the bark breaks at the bend; in some cases it helps to make an incision near the node; and sometimes a ring of bark is removed. In this way an independent plant may be developed, which in the course of a season or two is in a condition to be transplanted into a permanent bed.

32. **Grafting.** — The process of grafting is the insertion of a part of one plant into another so that the inserted part grows supported by the other plant. The inserted part is called the *scion*, and the plant upon which it is grafted is called the *stock*. The purpose of grafting is to propagate the scion, which represents the desired plant. There are several conditions that make grafting a desirable and even a necessary process. For example, in the case of fruit trees, to propagate a desired variety by seed is a long and uncertain process. Even if the time were short between seed-planting and fruit-bearing, often the seedlings do not come true and the fruit is not that which is desired. In the case of seedless fruits, grafting becomes necessary for propagation. Advantage is taken of grafting also to secure varieties of fruits in regions that are unfavorable to scion-plants. For example, peach trees thrive better in sandy soils of the southern states than do plum trees; therefore by using peach tree stocks and grafting into them plum tree scions, the plum varieties can be secured which otherwise would be impossible.

It is evident that the use of grafting is based upon the fact that the scion retains its individuality, so far as the character of its fruit is concerned. Much has been written concerning the influence of stock on scion, and of scion on stock, but in ordinary practice this influence is negligible. It is of scientific interest to discover how unlike plants may be and still enter into this union, but the fact of practical importance is that the more closely the two plants are related, the more successful is the grafting.

Grafting is a very old operation, and it has developed into very many kinds. In this connection it would be unprofitable to describe many methods, for such detailed knowledge is necessary only for those who are making a special study of grafting. A few common methods will be described, and they will serve to illustrate the principles involved.

Cleft-grafting is a method very commonly used with fruit trees (apple, pear, plum, cherry, etc.), when it is desired to use well-established stock plants to support varieties with more desirable fruit. The stock plant is cut off at a suitable place, the stump end is split a short distance and wedged, the wedge-shaped base of the scion is inserted so that cambiums of scion and stock are in contact, the wedges are removed, and the whole surface of the graft is covered with grafting wax, which protects the wound until it has healed and stock and scion have grown together. To double the chances of success it is very common to insert two scions into a single cleft, for the cambium is near the surface, and a scion on each side of the cleft will be in proper position (Fig. 14).

Fig. 14. — Cleft-grafting: in the left figure the scions are in place; in the right figure the graft is covered with grafting wax. — After Bailey.

The scions usually include three nodes (buds), and are cut from twigs of the previous season. These twigs are stored for a time in a cool place and pass into a dormant condition. It is customary to insert the scion so that one of the buds is at the surface of the graft, and this bud, although covered by the grafting wax, has the best chance to grow.

The use of a twig as a scion is what is ordinarily meant by grafting, and in addition to cleft-grafting, described above,

there is *whip-grafting*, in which scion and stock of equal size are spliced and lashed together (Fig. 15); *inarching*, in which two potted plants, for example, are brought together, and the scion is fastened to the stock without separation from the parent plant until union has been secured; *bridge-grafting*, in which the stock is girdled, and dormant scions, wedge-shaped at each end, are inserted at each edge of the girdle and bound in (Fig. 16).

Fig. 15. — Whip-grafting. — After Bailey.

33. **Budding.** — In addition to the use of twigs as scions, which may be called true grafting, it is very common to use buds as scions, a method which is bud-grafting, but is usually called simply *budding*. This consists in inserting under the bark of a stock plant a bud that has been removed from a scion plant. It is performed in spring or autumn, when the bark peels easily, and is frequently used, instead of twig-grafting, in the propagation of desirable races of fruits, especially of the stone fruits. The bud is sliced from its stem so as to include a little of the wood beneath; the leaves are removed from the stock in the region to be grafted; cross slits (usually like a T) are made through the bark of the stock; the base of the bud is slipped beneath the flaps of bark and bound in position; and in two or three weeks the bud "sets" and the wrapping is removed.

Fig. 16. — Bridge-grafting. — After Bailey.

All of the operations described in this chapter are merely illustrations of a very extensive practice of vegetative propagation. As opportunity offers, such operations should be witnessed in orchards, nurseries, greenhouses, etc. Furthermore, if suitable plants are available, some of the simpler operations should be undertaken by the students.

CHAPTER VI

PLANT-BREEDING

34. **Definition.** — By " plant-breeding " is meant the improvement of our old plants and the securing of new ones. Great advances have been made recently in our knowledge in reference to plant-breeding. These advances have largely been due to the fact that scientific men have been experimenting with plants to discover what are called the laws of heredity, and how new kinds of plants are produced. All this work of scientific plant-breeders has suggested to practical plant-breeders how their methods may be improved. Since a better and a more abundant food supply depends upon the progress of plant-breeding, it is evident that it is a subject of the greatest importance.

35. **Seed firms.** — The work of practical plant-breeding is done chiefly by establishments that have made it a specialty, and that provide improved races of plants and new plants for the use of those who cultivate them. For example, the farmer seldom works at plant-breeding, but secures his seed from " seed firms " that are equipped to do the more careful work that plant-breeding requires.

36. **Department of Agriculture.** — In addition to the work of the seed firms, the United States government, through its Department of Agriculture, does a vast amount of work in both scientific and practical plant-breeding, the results of which are for the benefit of all those who wish to cultivate plants. This Department also publishes a great many bulletins dealing with all kinds of operations connected with the cultivation of all kinds of plants, and these bulletins may usually be obtained for the asking. It would be a wise thing

for each school to secure a set of these bulletins dealing with the prominent crops of the vicinity.

37. **State Experiment Stations.** — The same sort of work and the same free distribution of information is going on at the various State Agricultural Experiment Stations, and the bulletins from the station in its own state should certainly be obtained by each school.

Although the national government and the state governments and the seed firms are all at work on the problems of plant-breeding, so that the cultivator of plants may take their results and use them, yet the intelligent cultivator should know something of the methods and possibilities of plant-breeding. This knowledge will at least give him a more critical judgment in reference to the claims made by the practical plant-breeders.

38. **Mass culture.** — The oldest method of plant-breeding is called *mass culture*, a method which has done much in securing improved races of plants. It may be explained by using wheat as an illustration. The plant-breeder selects some feature of the wheat he wishes to improve ; for example, its yield. He goes through a wheat field and selects the individual plants whose heads bear the largest number of grains. The grains from these selected plants are saved for seed, and in the next season they are planted and produce a crop. The plant-breeder goes through the new field and again selects the best individuals, and their grain is saved for seed. This selection goes on year after year, and each succeeding year shows a somewhat larger yield than the year before. Presently by this method of " continuous selection " the larger yield reaches a standard and a steadiness that enables the plant-breeder to announce an improved race of wheat, that is, a race improved as to its yield.

This method of plant-breeding has certain disadvantages that are obvious. It requires a great deal of time and labor, and when the improved race is put into the hands of an

ordinary farmer it does not stay improved very long. Unless the farmer uses great care in his own selection of individuals for seed, he will mix poor individuals with good ones and his succeeding crops will degenerate. For this reason, such farmers must apply frequently to the plant-breeders for a new supply of "guarded stock," that is, seeds from individuals that have been carefully selected and kept separate from the undesirable ones.

39. **Pedigree culture.** — Another method of plant-breeding that has come into prominence more recently is called *pedigree culture*, which means that a single plant is selected and its progeny carefully guarded, rather than hundreds of plants. It is the method ordinarily used in breeding fine animals. For a long time animals have not been improved by the pasture-full, but by the individual, whose pedigree is carefully recorded. It is a well-known fact that no two individuals are exactly alike, so that in even the most careful mass culture many kinds of individuals are mixed, and the result is an average. In pedigree culture it is not an average of many good individuals that is secured, but the very best individual.

The advantages of pedigree culture over mass culture are obvious. The selected individual is farther along in the right direction to start with, and so time and labor are saved; and also it is found that the result is more constant and less likely to degenerate. However, the best results are obtained by combining the two methods; for even after pedigree culture has selected out a desirable race, it may be improved by mass culture.

40. **Disease-resistance.** — In connection with pedigree culture it has become possible to combat disease and drought with remarkable success. These are the two most serious enemies to cultivated plants, and our annual losses from these two causes are very large. A few notable cases will serve to illustrate the method.

A few years ago the cotton fields of the southern states were attacked by a very destructive disease. When the ravaged fields were examined by experts, it was discovered that certain cotton plants were untouched by the disease; in other words, these individuals were immune to this particular disease. This fact suggested that this immunity might be a character that could be inherited, and so immune individuals were selected for breeding, and it was found that their progeny was also immune. In this way, by pedigree culture, immune races of cotton have been developed. It must not be supposed that an immune race is immune under all conditions, but this method enormously increases our success in preventing disease. This same method can be applied to all plants for all diseases, so that it is possible to look forward to the time when we will be cultivating only disease-resistant races of plants.

41. **Drought-resistance.** — A few years ago the wild original of our cultivated wheat was discovered in Palestine. This wild wheat grows in dry conditions, in situations that we would call " arid," such as are found in this country in New Mexico and Arizona. A drought-resistant wheat would be of the first importance, provided it was also of good quality. This combination of drought-resistance and good quality has now been secured through plant-breeding, so that it has become possible to insure wheat crops against drought. More than that, the drought-resistant wheat thus secured is found to be disease-resistant; that is, to the rust disease. This combination of drought-resistance, disease-resistance, and good quality promises to increase greatly the production of wheat.

A peculiar race of corn has been found in cultivation in China, which has a structure that makes it drought-resistant. Corn is peculiarly in danger of drought during the period when pollination occurs, and if a " dry spell " occurs at that period the corn crop is seriously damaged. If this drought-

resistant character can be combined with good quality of grain and good yield, the result will be of very great importance. This work is under progress, but the results have not been announced.

These illustrations from wheat and corn, our two most important cereal crops, indicate the possibility of breeding drought-resistant races of all the important cultivated plants.

42. **Corn-breeding**. — It would not be fair to give the impression that plant-breeding is a simple problem and that all plants can be handled alike. The breeding of corn will serve to illustrate how difficult the problem often is. A great deal of corn-breeding has been done, and it is still one of our most important problems, for corn is not only one of our most important cereals, but it is probably the most difficult one for the plant-breeder to handle. The ordinary field of corn is a remarkable mixture of different kinds of individuals, so that ordinary mass culture reaches very indefinite results. The discovery that the best method of selection is to select the best ears rather than merely the most vigorous individuals has resulted in a very largely increased yield. One difficulty in connection with corn, however, is that pollination is so free that under ordinary conditions it is beyond control. During the four or five days when a young ear is being pollinated, the pollen is flying freely from the tassels of many plants, so that some of the kernels of an ear may have received undesirable pollen. Therefore, after a good ear has been selected for seed, it may contain undesirable hybrid kernels. This means that selection must be continuous, not only to secure desirable individuals, but also to weed out undesirable hybrids. It is obvious that in this case pedigree culture deals with pedigrees known on the female (ear) side and only vaguely known on the male (tassel) side.

When rigid pedigree culture is applied to corn, so that pollination is accomplished under control, and a pure strain is secured, free from all mixture with other kinds of individuals,

it has been found that this pure strain deteriorates to a certain level; in other words, it is not so good for our purposes as the mixed races. In this case it is found that if two pure strains are crossed, the resulting hybrids are more vigorous than either parent. The ideal corn-breeding, therefore, is rather a complex operation, involving two distinct operations: (1) pedigree culture, which separates pure strains from a mixture; (2) combination of pure strains, which secures vigorous plants. The question might be asked, why is it desirable to separate pure strains from mixtures, only to combine them again in new mixtures? The answer is that unless the pure strains are separated and recombined, the mixtures are chance mixtures rather than intelligent mixtures. There are very many people, however, who prefer to use chance rather than intelligence.

43. **Hybridization.** — In the operations of plant-breeding described above, reference was made to "crossing"; that is, the use of two parent plants of different kinds, resulting in what is called a hybrid. *Hybridization* is a very important operation in plant-breeding, for by means of it certain desirable qualities that are separated in two kinds of plants may be combined in a single individual. It must not be supposed that the desired combination will appear in all of the hybrid progeny. It is only when thousands of hybrids are produced that there is any certainty that the desired combination will be found among them. But when it is found, the plant possessing it can be pedigreed and multiplied.

There is a limitation in the use of hybrids that must be noted. A hybrid combines characters of two parents, and when it produces progeny by means of seeds, only about one-half of the new individuals will continue the combination, that is, will continue to be hybrids. The other half will resemble one or the other parent. This is what is called the "splitting" of hybrids, and they split up in a definite ratio, which is called *Mendel's law*, and this same ratio of

splitting appears in each succeeding generation. In propagating a hybrid by seed, therefore, one may expect that in ordinary conditions only about one-half the progeny will show the desired combination.

It follows, therefore, that hybridization is most useful with those plants that are not propagated by seed, but by some vegetative method, as by tubers, bulbs, cuttings, layering, grafting, etc.; for in these cases one hybrid individual is continued directly in its progeny, without bringing in another plant as a parent. It is evident that the method can be used with great efficiency among the fruits, which are so largely propagated vegetatively; but that it is by no means so efficient among the cereals, which must be propagated by seeds.

A few illustrations will fix the method in mind. Seedless apples of poor quality have long been known, but by crossing seedless apples with those of good quality, a hybrid was produced which combined the two desired characters. It is evident that in this case vegetative propagation is necessary, so that there would be no danger of the hybrid splitting in the ordinary way.

The ordinary cultivated blackberry is large and black, but there is a small wild blackberry that is whitish or cream color. By crossing the two, a hybrid was secured that produced berries of the large size and light color, so that " white blackberries " could be grown.

The possibilities of such combinations are endless and many of them have been made, some more curious than useful, but many of them very useful.

Enough has been said to show that the operations of plant-breeding are exceedingly varied, and that by the use of various methods, either singly or in combination, almost any desired result may be obtained. It is becoming almost literally true that one may order almost any kind of plant and expect to have the order filled.

44. **Selection for regions.** — One important fact connected with plant-breeding needs to be emphasized. The natural tendency is for cultivators of plants to attempt to grow the same kinds of plants everywhere. If natural vegetation is observed, it will be observed that the assemblages of plants, technically known as the "plant population," differ in different regions, which means that nature does not attempt to grow the same plants everywhere. It is obvious that for every region there is the most suitable group of cultivated plants, that is, plants that will do the best. If this is considered, each region can be made to yield its maximum of plant products, which would greatly increase the total production of a large country like the United States.

45. **The food problem.** — The food problem is one of the most important problems of this country. It has become a problem because the rate of increase of population is much larger than the rate of increase of food production. It is evident that this inequality of the two rates must not be allowed to continue indefinitely. The recent developments in plant-breeding, indicated in the preceding paragraphs, together with the increase of knowledge in reference to the nature of the soil and its manipulation, outlined in Chapter III, make it possible to multiply many times the plant products of the country. This becomes evident if the following possibilities are realized:

1. Securing plants of largest yield and most desirable quality through the various methods of plant-breeding.

2. Securing disease-resistant races, by means of which frequent and great loss in plant products can be prevented.

3. Securing drought-resistant races, by means of which crops can not only be insured against drought where they are grown now, but their cultivation can be extended into new regions, especially those which have been regarded as too dry for such plants.

4. Selection for each region of the group of cultivated

plants best fitted for the conditions, by means of which the maximum yield of plant products can be secured for each region.

5. Cultivation of the soil in such a way that it may be kept in the best physical condition from the time of planting to the time of harvesting.

Experience has shown that when any one of these five possibilities is realized, the amount of plant product is much increased; and it becomes evident that when all five of them are realized throughout the country, our food production will be multiplied many times.

Another important factor that enters into the explanation of our diminishing food supply in comparison with our population is the persistent movement of population from the country to the cities, changing producers of food into mere consumers of food. Now that agriculture is becoming as scientific a profession as engineering or medicine, it is to be hoped that it will be attractive to an increasing number of vigorous young men, who might well recoil from the blind drudgery of the old-time farm, but will welcome the new and highly important science of agriculture.

CHAPTER VII

CEREALS AND FORAGE PLANTS

Cereals

46. **General statement.** — The cereals must be regarded as the most important crop plants of the world. They are grasses that have been brought into cultivation on account of the abundant starch stored in their seeds. This starch is not only the basis of our "bread-stuffs," but it also feeds the animals from which we obtain our principal meat supply, as well as those we use in other ways. The cultivation of cereals is the chief business of agriculture, so far as plants are concerned, and among the cereals are plants that have been cultivated throughout the whole recorded history of man. In fact, it was probably the cultivation of cereals, more than any other cause, that first transformed wandering tribes of men into settled, agricultural people.

The important cereals are corn, oats, wheat, barley, and rye, and the order given represents their relative importance in the United States at the present time.

In considering the cultivation of cereals in the United States, the student should know not only the methods of cultivation, but also the range of cultivation and the relative importance of each crop. The statistics given have been obtained from the most recent information in possession of the United States Department of Agriculture. They are given in round numbers, but they will reveal the relative importance of our cereals as at present cultivated. It must also be remembered that the amount of production varies from year to year, dependent upon what are called "good

years " and " bad years " for such crops. The cereals will be considered in the order of their importance in the United States.

Corn (Maize)

47. **Production of corn.** — A more appropriate name for Indian corn is " maize," the original name given to it when America was discovered. In foreign countries, " corn " means any grain and several things besides. " Indian corn "

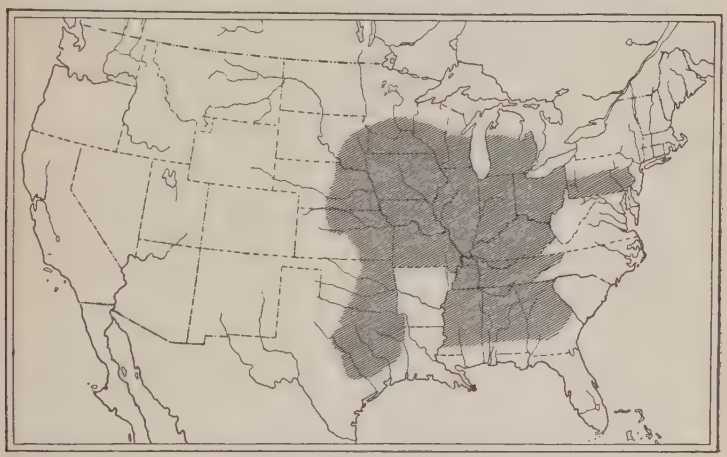


Fig. 17. — Map shaded to show the states of greatest corn-production.

distinguishes it from any other grain, but the simple word " corn " distinguishes it only in the United States.

The United States is preëminently the country of corn-production, in 1912 producing over three billion bushels. This statement is emphasized by contrasting this production with that of other countries, which will have to be done for the year 1911. In that year, a relatively poor year, the United States produced two and a half billion bushels of corn, while Italy, the second country in corn-production, produced 93 million bushels, and Russia 81 million bushels. In fact, in 1910 (the

last year for which returns from all countries are available), the United States produced nearly three-fourths of the corn of the world, a ratio which probably still holds.

FIG. 18. — Corn: the plant at the right shows the staminate flowers forming the terminal "tassel"; the plant to the left shows the "ear" (a close cluster of pistillate flowers) in the axil of a leaf and enclosed by the "husk," at the end of which the long styles ("silk") are exposed. — After DEVRIES.

The greatest corn-producing state is Illinois (about 335 million bushels in 1911), and the record for Iowa is almost as large (about 305 million bushels in 1911). No other states were reported as producing more than 200 million bushels in 1911, the order of the larger records being Missouri, Indiana, Nebraska, Ohio, and Kansas. In the government statistics referred to, 18 states are included as corn-producing states, the remaining 11, in the order of amount of production, being Kentucky, Tennessee, Minnesota, Texas, Pennsylvania, Georgia, Wisconsin, Michigan, Mississippi, Alabama, and South Dakota. This enumeration of states emphasizes the fact that the corn lands occur in the central and southern

states, or practically within the drainage system of the Mississippi River (Fig. 17).

48. **Structure of corn.** — Any one who cultivates corn should know something of its structure, which is quite different from that of the other cereals (Fig. 18). There are two kinds of flowers, one containing the stamens and the other the pistil. The staminate flowers form a spreading cluster at the top of the plant, constituting what is commonly called the "tassel." An examination of this tassel shows that it is made up of numerous small flowers, each one of which consists of bracts enclosing three stamens whose anthers are soon seen hanging downward, suspended by the long and slender filaments.

The flowers with the pistils are in a close cluster upon a branch from the axil of a leaf. It is this branch that forms the "cob," and upon it the pistillate flowers stand close together in longitudinal rows. The branch is ensheathed by large bracts, which later form the "husk" that invests the ear. Each flower consists of small bracts enclosing a single pistil, whose long, thread-like style forms the so-called "silk." It is the silk that receives the pollen from the stamens, and through the silk the pollen tube carries the male cell to the egg. In this way fertilization occurs, and as a consequence the grains begin to develop and later the mature "ear" is formed.

The danger from drought occurs when the pollen is flying, for at that time the silk must be moist to receive the pollen and to start the growth of the pollen-tube. Since four or five days are consumed in fully pollinating a single ear, which means that each silk must catch and hold some pollen, it is evident that a drying wind, or even dry air, will endanger the process. This is the most critical period for the corn crop, for blasted silk means failure of fertilization.

49. **Cultivation of corn.** — In the cultivation of corn, only general principles can be mentioned here. There are many

details that develop and should be learned in connection with the practice. The cultivation of no cereal has received so much attention in recent years, and, as a result, it is necessary for the corn-grower to keep informed as to the results of experimental work. Even the preparatory ploughing varies as to time and depth and other details.

While corn is grown on a great variety of soils, the best corn is produced upon deep, rich, well-watered and well-drained soils. A rich soil usually means one with a large amount of organic material in such condition that it is loose and friable, and not likely to cake in dry weather. A soil with such physical properties is often described as a "sandy loam." It has great capacity for receiving water and retaining it as soil films, and at the same time drains so readily that the circulation of the air is not interfered with. The depth and perfect physical condition of the soil demanded by successful corn-production is greater than for any other cereal crop. In preparing such a soil for seed, it is usually ploughed deeper than for any other cereal crop, but it is not certain that this is necessary.

In the greatest corn-producing states, the deeper, preliminary ploughing is generally done in the fall, and during the following May the seed-bed is finally prepared and planted. The time of planting is planned so as to escape the late spring frosts. The sowing is done either in hills or drills, but in any event it is done so that the soil can be worked between the rows of corn. The ground is kept pulverized with the harrow until the young plants appear; and afterwards the same pulverizing is accomplished by running cultivators of various kinds between the rows. This is continued as long as it can be done without injury to the plants, usually extending for about six weeks from the first of June.

50. **Selection of corn.** — Very much attention has been paid to the selection of seed corn, and to arouse interest and to develop facility in selection, as well as to stimulate interest

in agriculture in general, there has been an extensive organization of "corn clubs" for boys in rural communities. Reference has been made to these clubs (p. 320), but in this connection the principles of selection will be outlined briefly.

The two chief factors in the selection are a suitable plant and a suitable ear. The plant should be vigorous, with all its members (roots, stem, and leaves) well developed. The selected ear should be early maturing, large, sound, well shaped (carrying its diameter well from butt to tip), with straight and compact rows of grains, and a cob about one-half the diameter of the ear (Fig. 19). The selected ears should be stored in a dry place, with uniform temperature; and before planting the grains should be tested for vitality in a germinating bed, usually called a "tester." The direction for club work is that no lot of grains should be used for planting that do not show by the testing of samples that at least 95 per cent of them germinate promptly and vigorously.

FIG. 19. — Two ears of corn, showing a desirable ear for selection (at the left) and an undesirable ear (at the right); the former has been derived by selection from the latter.

51. **Corn-tester.** — There are several kinds of testers, but one that can be constructed in any school or home is the "sawdust box," which is exceedingly satisfactory (Fig. 20). A box three or four inches deep and about thirty inches square is recommended as a good size. This is half filled with thoroughly moistened sawdust (soaked for at least an hour), pressed down and with a smooth surface. Upon the sawdust

surface is laid a strong white cloth ruled in numbered squares with sides two or three inches long. This cloth is held in place by being tacked to the box. As many ears of corn can be tested as there are squares on the cloth, and each ear must bear a number corresponding to a numbered square. From each ear six kernels are removed: one from near the base of the ear, one from the middle, and one from near the tip, and three others in the corresponding positions on the opposite side of the ear. These six kernels, selected as samples of the entire ear, are placed upon the square of cloth whose number corresponds to that of the ear.

FIG. 20. — The "sawdust box" for testing corn: explained in text. — After Iowa State College Bulletin.

When all the kernels to be tested have been placed in their proper positions on the cloth, another cloth is laid over them and sprinkled. Then another cloth, larger than the box, is placed upon the sprinkled cloth, shaped as a lining to the box, and covered with two inches of moist and pressed-down sawdust, over which the edges of the large cloth are folded (Fig. 20). If kept in a warm place, the grains will germinate in about six days, when the cover is removed carefully so as not to displace them. The condition for examination is when shoots (stems) are about two inches long, and if it is discovered that the grains have been uncovered too soon, the covering should be replaced. Each ear is represented by six kernels, and if one or more of the kernels have

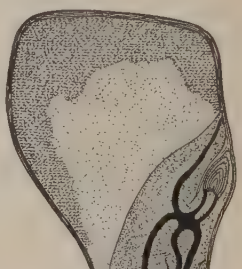


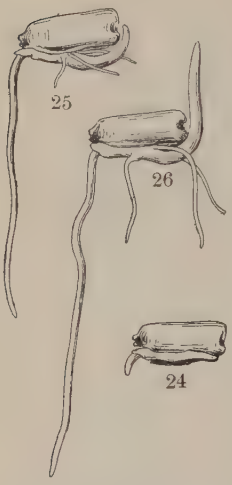
FIG. 21. — Section of a grain of corn: explained in the text. — After FRANK.

failed to germinate, or some of the seedlings are decidedly weaker than the others, that ear should be discarded.

The germination of corn is illustrated in Figs. 21–27. In Fig. 21 is shown a section of a grain of corn. Within the testa, the contents are divided into two principal regions, that to the right and below being the embryo, and that to the left and above, the endosperm, in which the food is stored. The position of the embryo is peculiar, for instead of being surrounded by the endosperm, it lies to one side of it. It will be noticed that the single large cotyledon of the embryo is in contact with the endosperm, from which it obtains food which it passes on to the growing parts that are to escape from the seed. In the embryo may also be seen the bud that is to produce the stem and leaves, and below it the hypocotyl that is to escape first and establish the root system. The cotyledon is attached at the joint which separates the young stem and the hypocotyl. The figure also indicates that the endosperm has two regions: the outer region (more deeply shaded) is the "horny endosperm," which contains protein food in addition to its starch; while the inner region (with lighter shading) is the "starchy endosperm." As the relative size of the two regions varies, the richness of the grain in protein or in starch varies. Figures 22 and 23 are slightly different views of a sprouting grain, showing the superficial position of the embryo, and that it simply splits a membrane (the testa) to be completely exposed. Figures 24–26 are all in the same position, Fig. 24 showing the tip of the hypocotyl turning towards the ground; Fig. 25 showing the great elongation of

FIGS. 22 and 23. — Two views of sprouting grains of corn, showing the relation of the embryo to the food supply; the "sprout" is the tip of the hypocotyl.

the hypocotyl, the beginning of growth and curving upward of the stem, and the putting out of roots; while in Fig. 26 the growth of all the parts has proceeded still further. In Fig. 27 is shown a young seedling established for independent work, with the root system started and the leaves beginning to unfold.



FIGS. 24–26. — Stages in the germination of corn: explained in the text.

The value of testing for vitality before planting is indicated by the following statement from a recent bulletin (February, 1913) issued by the State Agricultural Experiment Station of Iowa:

"Testing the vitality of seed corn before planting increased the profits per acre 93.6 per cent in 1910 and 85.7 per cent in 1911, or an increase of 19.6 bushels per acre in 1910 and of 10.1 bushels in 1911."

FIG. 27. — A young corn seedling just after germination has been completed.

52. **Sweet corn** — In addition to field corn of various kinds, there are the numerous races of sweet corn. Sweet corn is to be regarded as a vegetable rather than a cereal, but the soil conditions and the principles of cultivation are the same as for field corn. It is more intensively cultivated than field corn, and to this end it is planted in hills rather than drills, so that the soil all about it may be kept in condition. Canned sweet corn has become so common a food in North America that the demand for it

has developed extensive cultivation of sweet corn for this purpose, the leading states in the amount of this product being New York, Maine, Illinois, and Iowa, in the order named.

Oats

53. **Production of oats.** — The United States is also the leading country in the production of oats, in 1912 producing nearly one and a half billion bushels. The contrast with other

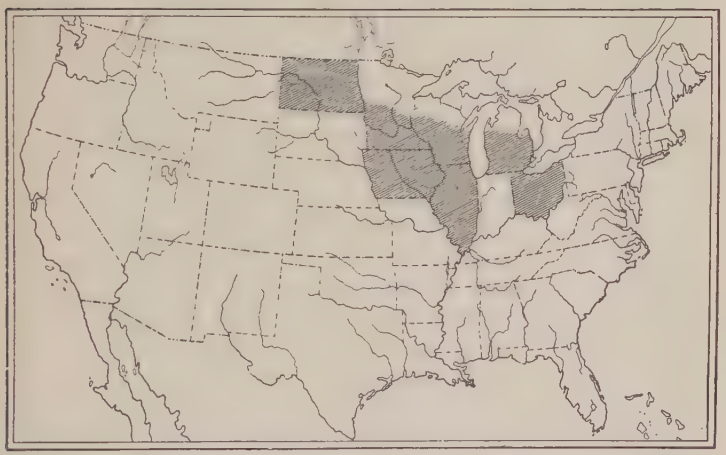


FIG. 28. — Map shaded to show the states of greatest oat-production.

countries may be illustrated by the crops of 1911, when the United States produced 922 million bushels, and Russia produced 858 million bushels. These two great oat-producing countries were followed by Germany with 530 million bushels.

Within the United States, Iowa and Illinois produce the largest amount, in 1911 Iowa producing 126 million bushels and Illinois 121 million bushels. This represents a little over one-quarter of the amount produced by all the states. The other states reported as oat-producing states, in the order of the amount of production, are Minnesota, Wisconsin, Ohio,

FIG. 29. — Oats, showing general habit of plant; flower cluster distinguished by being loose and branching, with each spikelet on a slender stalk.

and North Dakota. This means that the states of the Upper Mississippi Valley region produce most of our oats (Fig. 28).

54. **Structure of oats.** — The structure of oats is more like that of the ordinary grasses than is the structure of corn. The flowers are in a loose, branching cluster (*panicle*), each little group of flowers (*spikelet*) with a stalk of its own (Figs. 29 and 30). Each spikelet consists of two relatively large bracts (*glumes*) that surround usually two flowers (Fig. 30, *B*). Each flower consists of a pistil (whose ovary becomes the grain) and three stamens infolded by a bract (*palet*), and usually the palet of one of the flowers bears on its back (Fig. 30, *C*) a long, bristle-like appendage (*awn*). It is these awns that in many grasses, as the other cereals, form the so-called "beard." The prominent feature that distinguishes oats from wheat, barley, and rye is the loose, branching cluster of stalked spikelets. In these other cereals the spikelets stand close together on the main axis, forming the cluster called a *spike*, which is the so-called "head" of wheat, etc.

55. **Cultivation of oats.** — The oat is a hardy cereal, doing well in a cool climate and upon a light soil, and therefore it is grown chiefly in northern countries. In fact, it is not at all suited to the ordinary tropical conditions. The range of conditions in which it will grow is somewhat extensive, including light soils and heavy

soils, cool climate and warm climate, but it is not able to endure an excess of water.

In connection with the sowing of oats, the soil is not always ploughed when it is rich and deep, as corn land, but the seeds are sown broadcast and then covered by means of a corn-cultivator or a special harrow, being smoothed over afterwards by an ordinary harrow. Upon general principles, however, a good seed-bed should be prepared by ploughing, not necessarily so deep as for other cereals, and pulverizing. Most of the oats are sown early in the spring, so that most of the growth, which takes approximately three months, may occur during the cooler part of the growing season. Oats are also sown in the fall (" winter oats "), but this practice seems to be restricted to the more southern areas of oat-cultivation.

FIG. 30. — Oats, showing details of flower cluster: *A*, part of the cluster, showing the stalked spikelets; *B*, a single spikelet, showing the two glumes enclosing two flowers (a third abortive one is shown), each consisting of a pistil (whose branching style is shown) and three stamens infolded by the palet; *C*, the palets of the two flowers, one of them with a long awn. — After SARGENT.

Wheat

56. **Production of wheat.** — It is perhaps a surprise to some that the United States produces less wheat than oats, the amount for 1912 being 730 million bushels. Nevertheless,

it produces more wheat than any other country, Russia being second, and India third. In 1911 the product from these three countries was 621 million bushels in the United States, 509 million bushels in Russia, and 369 million bushels in India.

Within the United States, North Dakota produces the most wheat (about 73 million bushels in 1911), and the other wheat-producing states come in the following order: Kansas,

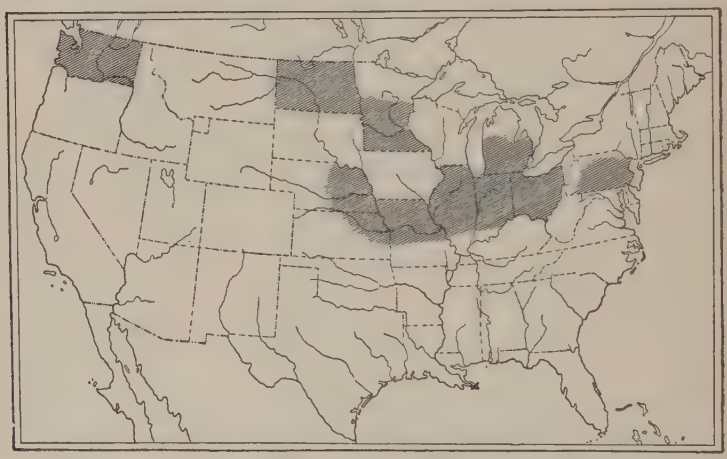


FIG. 31. — Map shaded to show the states of greatest wheat-production.

Washington, Minnesota, Illinois, Nebraska, Ohio, Missouri, Indiana, Michigan, and Pennsylvania. It will be noticed that these are all north central states excepting Washington (Fig. 31).

57. **Structure of wheat.** — It is easy to distinguish wheat (Fig. 32), with its spikes (heads), from oats, with its panicles (spreading clusters); but barley and rye also have spikes, and one should be able to distinguish wheat at sight from these cereals. Wheat and rye are alike in having a single spikelet at each joint of the axis; while in barley each joint bears three spikelets (one or two of which may be poorly developed).

The most obvious distinction between wheat and rye is that in wheat each spikelet contains several perfect flowers, while in rye each spikelet contains two perfect flowers. There are many races of wheat, but the conspicuous difference in the heads is that some are " bearded " (with awns) and some are " beardless " (without awns) (Fig. 33).

FIG. 32.—Wheat, showing general habit of plant; the flower cluster is a spike.

58. **Discovery of wild wheat.**—The cultivation of wheat is the oldest recorded agricultural operation, and wheat is perhaps still to be regarded as the most valuable of cereals. The wild original of the wheat was long sought for, and it was supposed that it had been so long in cultivation that it must have become very much changed and probably was represented in nature by some inconspicuous grass. It seemed clear that if wild wheat still existed, it would be found in western Asia. A few years ago a Jewish botanist found the wild original of wheat growing upon the rocky slopes of the mountains of Palestine, and it did not look very different from cultivated wheat. It is clear now that our ancestors who began the cultivation of wheat did not select an inconspicuous grass, foreseeing that it might be changed into a very useful plant, but took a grass that was plainly useful already. In fact, this wild wheat is a better plant for our purpose in several particulars than our cultivated races. It grows in thin and dry soils, quite unlike the soil necessary for the cultivated races of wheat, which have become pampered by being transferred to better soils. Not only is this wild wheat drought-resistant, but its vigor is further shown by the fact that it is not susceptible to the attack of the rust disease, one of the most

destructive diseases of our pampered and weakened races of wheat. It is obvious that this discovery of wild wheat, with its drought-resistant and disease-resistant qualities, is full of possibilities in the development of races of wheat suitable for the drier regions of our country, thus enormously extending the area of wheat-cultivation. In certain parts of these arid regions, what is called "dry farming" has been developed, which means the retention of moisture in the soil by proper tillage; and in these regions a race of wheat called "Durum" has been used with marked success. This Durum wheat is a race that is more closely related to wild wheat than any other cultivated race, and for this reason it is more drought-resistant than the ordinary races.

FIG. 33.—"Bearded" and "beardless" wheat. — After Internat. Encyl.

59. **Cultivation of wheat.** — Wheat has been cultivated for so long a time and under so many conditions that it has more varieties or races than any other cereal, and to select the best race of wheat for a given area demands the judgment of an expert. There are spring and winter wheats, bearded and beardless wheats, soft and hard wheats, etc., and new races of all of these are being announced almost every year.

The cultivated wheats require good soil, better than oats will thrive in, and a thoroughly pulverized soil, so as to secure a high degree of water-holding capacity, and at the same time good drainage.

In preparing the soil for winter wheat, it is ploughed four or five inches deep, then pulverized, and allowed to settle before the seed is sown. The seed is often sown broadcast and then covered with a harrow, but more commonly now it is drilled, a method which secures more even distribution and more uniform depth. Wheat is a hardy plant in enduring cold,

but the best protection of young winter wheat is a covering of snow, under which it can endure freezing temperatures. The greatest danger to winter wheat is the alternate thawing and freezing of an unprotected soil.

Spring wheat is sown as early as possible, to secure the cooler part of the growing season for the principal growth, and usually upon soil that has been ploughed the previous autumn, or often without ploughing upon a corn-field of the preceding

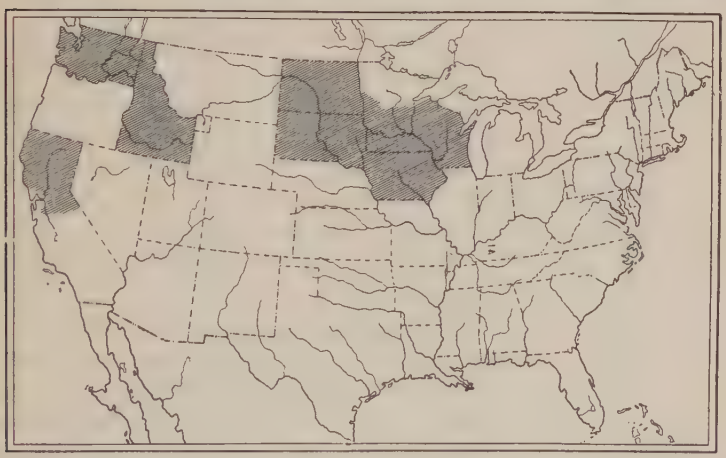


FIG. 34. — Map shaded to show the states of greatest barley-production.

season. In the case of ploughing and preparing a seed-bed, the seed is broadcast or drilled as described above. In the case of planting among corn-stubble, it is broadcast and covered by a corn-cultivator and frequent harrowing.

Barley

60. **Production of barley.** — The great barley-producing country of the world is Russia, which reported 411 million bushels in 1911; while the United States came second with only 160 million bushels. In 1912 the United States produced 224 million bushels.

Within this country, California produces the most barley (about 40 million bushels in 1911), and the other barley-producing states come in the following order: Minnesota, North Dakota, Wisconsin, Iowa, Washington, Idaho, and South Dakota. It is evident that the production of barley is not restricted by suitable conditions, but by lack of general interest (Fig. 34).

FIG. 35.—Barley, showing general habit of plant and character of spike.

61. **Cultivation of barley.** — Barley is also a cereal of very ancient cultivation, and has been found in its original wild state in western Asia (Fig. 35). Its range of cultivation is very great, extending farther north than the usual range of wheat, and extending southward into tropical conditions. It also grows quickly, and therefore can be used in regions of short growing seasons.

The soil conditions and preparation are approximately the same as for wheat. Most of our barley, at least in the northern states, is sown in the spring. Barley is a little more sensitive to cold than wheat, so that in regions where wheat, oats, and barley are grown, the order of planting is first spring wheat, then barley, and finally oats. The methods of sowing (broadcast and drill) are the same as for wheat.

The cultivation of winter barley is increasing rapidly, because it gives a better yield than spring barley, and is a more certain crop. At present its cultivation is chiefly in the states south of the Ohio and Platte rivers and those west of the Rocky Mountains. The Department of Agriculture has indicated those states in which only spring barley can be

grown, those in which only winter barley can be grown, and those in which both can be grown.

Rye

62. **Production of rye.** — The United States makes its poorest showing, so far as cereals are concerned, in the cultivation of rye, coming fifth in the list of rye-producing countries. Russia is far in advance of any other country, with

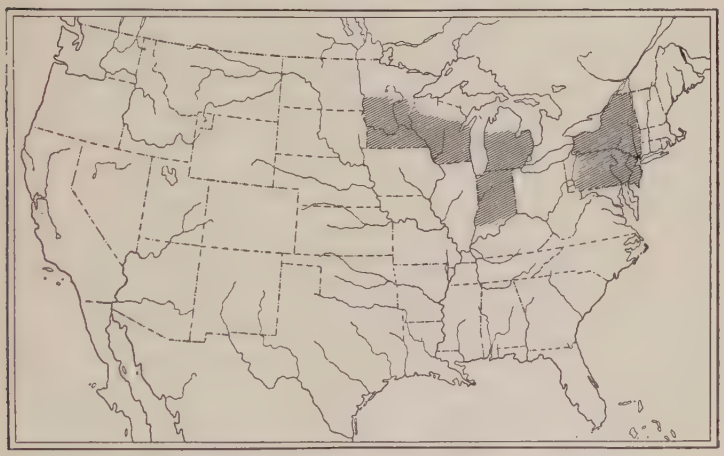


Fig. 36. — Map shaded to show the states of greatest rye-production.

762 million bushels in 1911, followed by Germany with 427 million bushels, then Austria-Hungary, France, and the United States (33 million bushels). In 1912 the United States produced 35 million bushels, the most productive state being Wisconsin, followed by Michigan, Minnesota, Pennsylvania, New York, New Jersey, and Indiana (Fig. 36).

63. **Cultivation of rye.** — Rye seems to have been introduced into cultivation later than the other cereals, for the records of it do not extend beyond the Roman agriculture. For this reason, probably, there are fewer kinds of rye than

of any other cereal (Fig. 37). Its great feature in cultivation is that it will grow in soil too poor for any other cereal. It cannot grow so far north as barley, but it can ripen in latitudes too cold for wheat. However, it thrives best where wheat thrives, but as it is not so valuable a crop, it does not replace wheat.

Fig. 37. — Rye, showing general habit of plant (upper part of stem omitted) and character of spike.

It is usually cultivated on light, sandy soils, not doing at all well on wet and heavy soils. As in the case of the other cereals, there are spring and winter ryes, the latter being most frequently used, and usually ripening in June. The preparation of the soil, the planting, and the cultivation are the same as for the other cereals.

Rice

64. **Production of rice.** — If the important cereal crops of the whole world were being considered, rice would have to be added, for it is estimated to supply the principal food of one-half the human race. But very little of the rice of the world is produced in the United States (715 million pounds in 1911), and its production is restricted practically to the Gulf states and Arkansas, with Louisiana producing by far the largest amount (Fig. 38). The greatest rice-producing country in the world is India (about 89 billion pounds in 1910), and Japan is the next in our records (about 15 billion pounds in 1910). The statistics of rice-production in China are not available, but it must be much greater than that of Japan; and Egypt is also a great rice-producing country.

65. **Structure of rice.** — The appearance of the flower cluster of rice is intermediate between that of barley and oats (Fig. 39). The spikelets are in a panicle, as in oats, but the

branches of the panicle are erect and often crowded, not spreading, as in oats, but not compact and looking like a spike, as in barley. There is a single perfect flower in each spikelet, and the hard palet encloses the grain so closely that it falls with it, forming the so-called "husk" about the grain (Figs. 40 and 41). Rice with the husks on is often called " paddy," while in India all rice is " paddy."

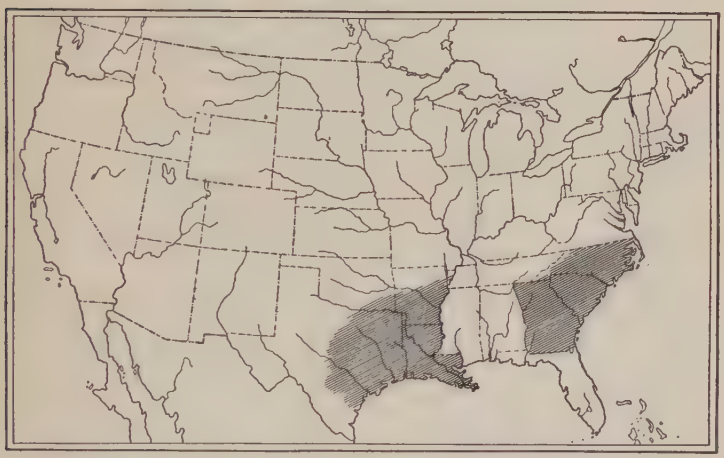


Fig. 38. — Map shaded to show the states of greatest rice-production.

66. **Cultivation of rice.** — The cultivation of rice belongs to subtropical countries, and it requires wet soil, which can be artificially flooded at certain times. There are also " upland " varieties which do not require flooding. In the warmer countries two crops a year are raised. The seed is sown on very wet soil, then transplanted to its permanent place, and flooded at intervals. In the United States the rice lands are prepared as for other cereals, and either put under irrigation control, or lowlands are used that are subject to flooding. Of course the upland rice is cultivated in the dry way used with other cereals.

Forage Plants

67. **Definition.** — Forage plants are those used as food for farm animals, and their cultivation forms a very important part of agriculture. Foods for animals have been developed recently in such variety that they have extended far beyond the range of forage plants, but the latter are the only animal foods that come within the purpose of this book. Forage plants also include those that are not cultivated primarily as animal foods, as, for example, the use of corn fodder, straw, and cereal grains as such foods. These have been considered under the head of cereals.

Fig. 39–41. — Rice: Fig. 39, the flower cluster; fig. 40, a single flower, with its bracts; fig. 41, bracts removed, showing the grain infolded by the husk. — The single flowers after Baillon.

68. **The grass family.** — The most ancient forage plants are the grasses, and every one is familiar with their use for grazing and for hay. Until recently, hay always meant dried grass, but other kinds of hay (dried plants) have been added. Naturally the grasses are still the most used forage plants, for pastures (for grazing) and meadows (for cutting) occur extensively in nature and involve the least amount of cultivation. Conspicuous among the grasses that have been cultivated for pasture and meadow purposes are redtop, timothy, and Kentucky blue grass, and samples of these three grasses should be examined, so that they can be recognized.

69. **The legume family.** — In addition to the grasses, there

are three great forage plants, which are used also for other purposes. They are clover, alfalfa, and cow-pea, and any outline of agricultural operations which does not include these great crops would be incomplete. They all belong to a single great family (Leguminosæ), and associated with them are such familiar plants as sweet peas, common peas, beans, peanuts, and such trees as the locusts and redbuds.

These three forage plants have a very important character in common, which can be described for all of them. They are all able to use the free nitrogen of the air by their peculiar association with the nitrogen-fixing bacteria of the soil. This means that instead of drawing upon the very important nitrates of the soil, they can add to the nitrates and thus enrich the soil. For this reason they can be used to restore soil that has become impoverished in its nitrogen supply by other crops. It is customary, therefore, to alternate crops of these clover-like plants with other crops, notably the cereals, the process being called "rotation of crops." In other words, these forage plants are very commonly used as the "alternating crop" which restores the soil to good condition.

These plants are not only useful in adding nitrogen compounds to the soil, but they are also remarkably deep rooted and leave the soil in better physical condition. The deep-rooting not only puts the soil in better physical condition, but it facilitates the movement of salts towards the surface, so that the result of such a crop is not only an accumulation in the superficial soil of nitrogen compounds, but also of other important soil salts.

Another very common use to which these plants are put, a use which depends upon their rich contents of valuable salts, is what is called "green manuring," which means that the plants are ploughed into the soil and contribute their whole bodies to enriching it.

70. **Clover.** — There are a good many clovers, but the most valuable one as a forage plant is the red clover, whose

FIG. 42. — Red clover.

appearance, with its three leaflets (each usually with a pale spot on the upper surface) and head of rose-purple flowers, should be familiar to every one (Fig. 42). It is extremely valuable for the many purposes it serves, such as hay, green fodder, pasturage, green manuring, but its chief value is in enriching the soil, as described above. It is used also as a "cover-crop" in orchards, which means that it can cover the soil in such a way as to hold the moisture, at the same time enriching the soil. Later it is "ploughed under," and it contributes still more to the soil.

Red clover can grow in a variety of soils and climates, but at present its most extensive agricultural use is in the northern states.

71. **Alfalfa.** — This forage plant (called also lucerne), a native of western Asia, and long cultivated in Europe, has become extensively cultivated in the western states (Fig. 43). It was introduced into California about sixty years ago, and its cultivation has extended rapidly over the arid regions of the Pacific and Rocky Mountain states, where it is grown more extensively than any

FIG. 43. — Alfalfa, showing the general habit, a single flower, and the curiously coiled pod. — After Ill. of British Flora.

other forage crop. Its cultivation is extending still further east, and it bids fair to replace red clover in many of our northern states.

The best soil for alfalfa is a rich, sandy, well-drained loam, and this makes it especially favorable for the rich soils of the dry west where irrigation is used. It is a plant one to three feet high, with clover-like leaves, and purple flowers in long, loose clusters. In loose soils the tap-root is said to reach a

Fig. 44. — Cow-pea. — After Engler and Prantl.

depth of ten to twelve feet, and cases of 50 feet in depth have been reported.

The seeds are sown broadcast or in drills, and the young plants are rather tender, so that care is necessary to establish a field, which usually requires two years, but after it has been established it is quite enduring. The ordinary yield of hay is reported to be three to eight tons per acre, and sometimes a yield of ten to twelve tons per acre is reached.

72. **Cow-pea.** — Cow-pea is to the south what clover is to the north and alfalfa to the west. It is an important hay

crop and soil-renovator in the south, and it is grown to some extent in the north (Fig. 44). It is a bean, rather than a pea, closely related to the ordinary garden bean, and the beans are often used for food. In the south the plant grows as a vine, but it becomes bushy in the north.

73. **Suggestions for work.** — It is evident that the growth of cereal and forage crops cannot be made a part of the work of the student. Much of this chapter, therefore, must be used as information concerning these very important crops. However, two things should be done, which will form an introduction to crop-raising. The first thing is to learn to recognize the cereals and forage plants mentioned in this chapter. It is easy to secure samples of the plants and to learn their distinguishing features. The second thing is to germinate and test some of the seeds, so that this very important preliminary performance may be learned through experience. Information about a process can never take the place of experience. Information merely suggests how the process may be undertaken, but experience encounters all of the details that are necessary to secure the result.

CHAPTER VIII

VEGETABLES

74. **Definition.** — There is no exact definition of the word *vegetable*. Its application is a matter of usage, including the greatest variety of plant structures. Even the same plant product may be called a vegetable or not; for example, corn is either a vegetable or a cereal, dependent upon the manner of using it. While the cereals all belong to one great family, the grass family, and all the principal fruits belong to two or three families, vegetables belong to a great number of families. In the following pages representatives of ten families will be presented as being included among vegetables, and these are selected only as samples.

Most of the vegetables are cultivated in all countries, but each country is characterized by the emphasis it places upon certain vegetables. For example, sweet corn, sweet potatoes, tomatoes, and watermelons are cultivated more extensively in the United States than anywhere else in the world. These four " vegetables " will serve to illustrate the great variety of structures covered by the name: one is a seed, one is a root, and two are fruits. If to these we add cabbage and lettuce, which are leaves, onions, which are bulbs, and potatoes, which are tubers, we find that at least six different plant structures are included in the term *vegetable*.

75. **Suggestions for work.** — In connection with the work of this chapter, not only ought some of the quick-growing vegetables to be cultivated, but as good a collection of vegetables ought to be brought together as the neighborhood affords. An interesting " field trip " consists in visiting some large market, where the different vegetables can be recog-

nized. It is surprising how many young people there are who can recognize vegetables when served on the table, but who cannot recognize many of them as they appear in the markets.

In the following account of some of the more common vegetables, suggestions as to cultivating them are often included, not because pupils can do such things in connection with this study, but because they should know something of such details, and chiefly with the hope that some of them may be interested in cultivating home gardens.

76. **Gardening.** — The cultivation of vegetables is usually called gardening, as distinct from farming. A few generations ago almost every family had a home garden, the products of which were for family use. In general, this was amateur gardening, and the results were extremely variable. There was no opportunity to select especially favorable soil and climate, for the garden had to be near the home. The general purpose was to secure good quality, a continuous supply, and as great variety as possible.

With the growth of large cities a new phase of gardening was developed, known as market-gardening or truck-gardening, the products being for sale just as are the products of a factory. This kind of gardening became professional, and the product became very uniform in standard. In establishing an industry of this kind, it was possible to select the most favorable soil and climate, sometimes within easy reach of the market, sometimes at great distances from it. The general purpose of a market garden is to secure uniformity, high productiveness, quick growth, and comparatively few crops.

77. **Garden soil.** — There is a general uniformity in the character of good garden soil, no matter what vegetables are to be cultivated. The soil should be not only rich in the materials for plant food, but also light and loose, which means good drainage. Such a soil is called a " quick " soil because

it enables plants to start early and to develop rapidly. Of course it must be tilled thoroughly and kept so. The plants are also stimulated to rapid and vigorous growth by the free use of suitable fertilizers, the best one being stable manure. Where intensive gardening is practised, many vegetables are started under glass and transplanted as soon as the weather permits (as cabbage, early celery, sweet potatoes, tomatoes, early lettuce), thus securing a much earlier crop.

78. **Classification of vegetables.** — It would be impossible and unprofitable to enumerate the very numerous vegetables in use. Some of the most common ones must be selected as representatives. Any one who knows how to cultivate these representative forms can extend the same principles to the cultivation of any vegetable.

Instead of classifying vegetables by the plant families to which they belong, it will be more useful to classify them by the plant structures they represent. This is more useful because it is the structures that determine the methods of cultivation and not the families. The six structures referred to above will be used: (1) *tubers*, represented by the potato; (2) *roots*, represented by the radish, turnip, parsnip, carrot, beet, and sweet potato; (3) *bulbs*, represented by the onion; (4) *leaves*, represented by cabbage, lettuce, and celery; (5) *fruits*, represented by the tomato, cucumber, pumpkin, squash, and melons; (6) *seeds*, represented by peas, beans, and sweet corn. Of course this list probably does not include all of the vegetables cultivated in any locality, but it includes the principal ones.

Tubers

79. **Potato.** — This is the most widely cultivated and valuable of the tubers used as vegetables. The potato tuber is a thickened branch of an underground stem (Fig. 45), and it shows its stem character by its "eyes," which are buds in the axils of minute leaves (scales). America is the native

home of the potato, the wild plants occurring in the mountains and highlands from southern Colorado, through Mexico, and south into Chili.

Although potatoes originated in America, they are not so extensively used in the United States as in Europe. For example, in the ten years extending from 1880 to 1890, the average annual crop of the United States was 170 million bushels, while that of Europe was over two billion bushels. In 1912, however, the crop of the United States had become 421 million bushels. In 1911 the greatest potato-producing states were Wisconsin (32 million bushels), Michigan (31 million bushels), New York (28 million bushels), Minnesota (26 million bushels), and Maine (21 million bushels).

FIG. 45. — The potato plant, showing the lower part of the stem, the tubers, and the roots. — After SARGENT.

The potato belongs to the nightshade family (Solanaceæ), and in its genus (*Solanum*) occur not only the poisonous nightshades, but also the edible egg-plant; while some of its associates in the family are tomato, red pepper, belladona, petunia, and tobacco. The flower of the potato plant (Fig. 46) can be recognized by the blue or white corolla, which has five broadly spreading lobes (" wheel-shaped "); and its five stamens grouped together about the style, with anthers opening by a hole at the top. The fruit produced by the flower is a round green berry. The leaves are pinnately compound, with minute leaflets intermixed with the large ones.

The best soil for potatoes is a rich, sandy, well-drained loam, forming a light soil, and this is indicated by the fact

that those states in which such a sandy soil occurs in abundance are the largest producers. Of course potatoes are grown in cold, damp soil, but they are produced more quickly and of better quality in rather dry and sandy soils.

Cutting the tubers for planting has been described (p. 326). Each piece should include one or two eyes with as much of the tuber attached as possible, so that there may be abundant food to start the young plants vigorously.

FIG. 46. — The potato plant: *a*, foliage and flowers; *b*, single flower; *c*, stamen, showing the terminal pores through which the pollen is shed. — After BAILLON.

Early potatoes should be planted as soon as the danger of frost is past, for potatoes are sensitive to frost. The cuttings are planted two or three inches deep, in dry and warm soil, and in tilling the ground is kept level until the plants are nearly full grown. Then the rows are " hilled," which makes the soil warmer and drier, and secures an earlier development of tubers.

Late potatoes are planted three or four weeks after the early ones, and somewhat deeper, and there must be frequent level

tillage to retain the soil moisture during the hot weather when the tubers are maturing.

There are hundreds of varieties of potatoes, new ones constantly replacing old ones. These new varieties are usually produced under exceptionally favorable conditions, so that in ordinary cultivation they degenerate ("run out"). It is for this reason that many of the most notable varieties of a generation ago have been replaced by new ones.

Roots

80. **Radish.** — This is one of the most popular vegetables, because it grows quickly and is ready for use very early in the season. Since it can be grown at any season of the year and develops in so short a time, it is one of the best garden plants for use in school gardens, as well as in home gardens. The radish belongs to the mustard family (Cruciferæ), which contains many common wild flowers as well as useful plants. Associated with the radish in the same family are such useful plants as the mustards, water cress, horseradish, cabbage, and turnip. The family is recognized by its four petals (purple and whitish in radish), its six stamens (two of them shorter than the other four), and its pod fruit, which in the radish is at first fleshy and then becomes dry and corky (Fig. 47).

The races of radish differ in size, shape, color, and texture, as any one who sees them in market will recognize (Fig. 48). The crop is much more uniform if the seed is sifted to get rid of the small and imperfect seeds and of foreign particles that are apt to occur in any package of seeds. The richer and looser the soil, the better. Spring radishes should be sown as soon as the ground can be worked, for the plants are very hardy, and radishes will be ready for use in three to six weeks. In a week or two later they become pithy, so that repeated sowings are necessary for a continuous supply. Summer radishes are of slower growth, and therefore keep longer in condition;

while winter radishes, whose seeds are sown from the last of July to the middle of September, are still slower in developing, and may be kept in good condition almost as long and as easily as turnips. The planting of the seeds is the same as for many garden crops; that is, they are sown in rows five to eight inches

FIG. 47. — A flower of cabbage (mustard family): *A*, flower cluster, showing buds at tip, open flowers below with four spreading petals, and pods at the bottom; *B*, a mature pod; *C*, a pod opening. — After WARMING.

apart, and when the plants appear, so that relative vigor can be recognized, they are thinned so that the individual plants stand about two or three inches apart in each row.

81. **Turnip.** — The turnip (Fig. 49) is very closely related to the radish, and those who can grow the latter should have no trouble with the former. There are early turnips,

sown as soon as the ground can be worked, for use in the late spring and summer; and late turnips, sown very late and stored for winter use. In the home garden, the seeds are planted in rows ten to twenty inches apart, and afterwards the plants are thinned to six to ten inches apart in the rows. Turnips are such hardy plants that they require no special care in cultivation.

Fig. 48. — Radish.

Turnips, however, are often grown as a field crop, to be raised on a larger scale, either for the market or for feeding. In this case the rows are farther apart (about 30 inches), so that a horse may be used in tilling the soil. It is reported that sometimes the yield of turnips reaches 1000 bushels to the acre.

82. **Beet.** — The beet belongs to a family of homely weeds, known as the goosefoot family (Chenopodiaceæ), and about its only useful associate is spinach. The inconspicuous flowers occur in clusters which form a spike; but the leaves are large and sometimes purple tinged, and are often used for "greens."

Fig. 49 —Turnip.—After Bailey.

Young beets form an important early crop of the market gardens, often many acres being employed in their cultivation. The soil needed and the tillage are the same as for other root crops. The first sowing is done as soon as the soil can be worked, and the usual rows (about a foot apart) are established, followed by the usual thinning (to about six inches apart). Of course when horse cultivation is desirable, the rows must be farther apart (two to three feet). There is also

a fall crop, for winter storage, the seed for which is sown in June.

83. **Sweet potato.** — This is a root crop that differs in several particulars from those just described. Sweet potatoes are often mistakenly called tubers. The ordinary potato is a tuber, that is, a thickened underground stem; but a sweet potato is a thickened root, and is not a tuber any more than radishes, and turnips, and beets are tubers. In these three plants just mentioned, the "vegetable" is the thickened tap-root; while sweet potatoes are thickened root branches.

The sweet potato is a morning-glory, in which genus (*Ipomœa*) there are many showy cultivated plants. The family is called the convolvulus family (Convolvulaceæ). The sweet potato plant is a trailing vine whose branches root at the joints (Fig. 50), or it may be cultivated as a bushy plant. The potatoes are borne close together under the crown of the plant, that is, just below where the stem merges into the root, or where the joints "strike root." Since sweet potato is a morning-glory, there should be no difficulty in recognizing its conspicuous funnel-shaped, purple flowers (Fig. 50). The leaves are quite variable, having a general triangular outline, and often heart-shaped at base.

Fig. 50. — Sweet potato.

Sweet potatoes are more extensively cultivated in the United States than in any other country, the annual yield being about 50 million bushels. They need a warm, sunny climate, a long growing season, loose, warm soil, and plenty of moisture. These conditions are found in our southern states, and therefore sweet potatoes as a commercial crop are

grown almost exclusively in the southern states, from Virginia around to Texas. The most northern state in which they are grown on a large scale is New Jersey; and fairly large crops are produced in Ohio, Indiana, Illinois, and California.

Fig. 51.—Sweet potato, showing the character of flower and leaf.

Propagation is by means of sprouts that develop from the potatoes when they are planted in propagating beds or frames. These root sprouts are used as slips or cuttings. Sometimes cuttings are also obtained from the tips of fresh runners. The plant is very sensitive to frost, and there is often great loss on account of planting too early. The sprouts are set in rows about four feet apart, the plants in each row being about 18 inches apart. A good average yield is said to range from 200 to 400 bushels an acre, and the crop is harvested immediately after the first frost.

Sweet potatoes are often raised in the northern states on a small scale as a home garden crop. In this case, looseness and warmth of soil are secured by planting the slips on ridges of soil.

Fig. 52. — Carrot.

84. **Parsnip and carrot.** — These vegetables are the thickened tap-roots (Fig. 52) of two plants belonging to the parsley family (Umbelliferæ). They are introduced here not so much on account of their importance, as to illustrate root crops from another family of plants. The family is a large one, including, along with parsnip and carrot, such well-known forms as coriander, fennel, caraway, hemlock, and

celery; in other words, vegetables, aromatic plants, and poisonous plants. The family receives its name from its characteristic flower-cluster (*umbel*), which is flat-topped, the individual small flowers or groups of flowers standing on branches (rays) that arise from a common point and spread like the rays of an umbrella. Wild carrot, with its umbels of small white flowers, is one of our bad weeds; while wild parsnip, with its umbels of small yellow flowers, is very common.

The cultivation of parsnips and carrots is in general the same as for such root crops as turnips and beets, but they are slow-growing plants and it is a long time between the sowing and the harvest.

Bulbs

85. **Onion.** — The best-known edible bulb is the onion, probably a native of western Asia and brought into cultivation in very ancient times. Onions, leeks, and garlic belong to one genus (*Allium*), which is a member of the lily family (Liliaceæ). Among their associates in the family are such ornamental plants as the lilies, tulips, and hyacinths, and the well-known vegetable, asparagus.

The necessary soil is the usual good garden soil, and thorough cultivation is required. Onions are very hardy, and in the northern states the seeds are sown or the bulbs planted as soon as the ground can be prepared properly in the spring; in fact, it is common to get a good start by preparing the ground in the fall.

The seeds are small and do not germinate quickly, and great care has to be taken to keep the beds free from weeds, as onions cannot stand such competition. The seeds are sown thickly in rows, and afterwards the young plants are thinned out so as to be properly spaced.

It is more common to propagate onions by "sets," especially for early onions, and sets are of three kinds: (1) "top

onions," which mean the bulblets that appear in the flower-clusters; (2) "multipliers" or "potato onions," which mean the separate parts or cores in which a bulb often develops; and (3) ordinary bulbs arrested in growth, sometimes called "stunts." The top onions quickly produce young bulbs, and these are the "young onions" that appear in market. The stunted bulbs are produced from seeds, by sowing very thickly in rather poor soil. In such conditions the bulbs soon reach their limit of growth and are harvested, kept over winter, and planted in more favorable conditions the next spring.

Leaves

86. **Cabbage.** — This plant has been very long in cultivation, and grows wild on the sea-cliffs of western and southern Europe (Fig. 53). From this wild plant, such different-looking forms, as the various cabbages, cauliflower, Brussels sprouts, etc., have been derived (Figs. 54–60). It belongs to the mustard family (Cruciferæ), and its well-known associates are enumerated in the account of the radish (p. 372).

FIG. 53. — The wild cabbage growing on a cliff. — After BAILEY.

Cabbages can grow in almost any kind of soil, but they must have plenty of food and water, though not an oversupply of the latter. Hot and dry air does not prevent growth, but it does prevent the formation of "heads," which are merely large buds. For this reason, heads do not form well in the summer weather of the United States, and hence in the north seed-sowing is timed to avoid "heading" in hot weather, while in the south the plants are grown during the winter and spring months.

FIGS. 54–60. — Some of the forms derived from wild cabbage: Fig. 54, wild cabbage; Fig. 55, cultivated cabbage; Fig. 56, cauliflower; Fig. 57, Brussels sprouts; Fig. 58, kale; Fig. 59, kohl-rabi; Fig. 60, collards.

The earliest varieties develop in about three months from seed, and the later varieties extend this period up to six or seven months. The seeds are sown in boxes in the usual rows, and then transplanted into the permanent bed. If they are to be set out in March, the seed is started early in February. For later crops the seed is sown out of doors in a well-prepared germination bed, which is repeatedly raked to hold moisture until the plants are removed to their permanent place.

87. **Lettuce.** — This is the most popular salad vegetable and grows so quickly that it should be one of the forms used in school work. It belongs to the largest family of flowering plants (Compositæ), a family which is also the highest in rank, which means that it is regarded as the most highly organized family in the plant kingdom. Some of the familiar associates of lettuce in this great family are such ornamental plants as golden-rods, asters, daisies, sunflowers, dahlias, and chrysanthemums; such weeds as ragweed, cocklebur, thistle, and dandelion; and such useful plants as chicory and artichoke.

The family is characterized by its compact head of flowers, which is thought of by most persons as a single flower (Fig. 61). But if the so-called flower of dandelion or sunflower be examined, it will be discovered that it consists of numerous very small flowers packed together upon a flat disk (*receptacle*), and the whole assemblage of flowers surrounded by a rosette of small leaves (*involucre*).

There are two general types of lettuce in cultivation: (1) head lettuce, which heads up like cabbage, and (2) loose lettuce. The latter is more used because it is grown more easily, but the former is regarded as the finer. Since the value of lettuce depends upon its freshness, it is grown almost universally in home gardens, and a very small area yields enough to supply a family. There is no vegetable grown so easily in sufficient quantity in city backyards. The proper

FIG. 61. — The head (so-called "flower") of a composite (*Arnica*): *A*, a plant showing an open head; *B*, one of the flowers that make up the margin of the head; *C*, one of the flowers that make up the center (disk) of the head. — After HOFFMAN.

thing is to secure as long a succession of fresh lettuce as possible. In early spring, about when the grass is starting, a suitable area should be spread with fine manure, and then the soil pulverized and smoothed over. A furrow about an inch

deep is marked in the fine soil, the seeds are dropped in (twenty-five to fifty in a foot), and then covered with fine and pressed-down soil. In fifteen to twenty days the plants are thinned out, leaving eight to ten in a foot; and at the same time a second row is planted. About twenty days later the first row is thinned again, so that the plants are six to twelve inches apart (according to size); the second now receives its first thinning; and a third row is started. Even a fourth row may be started, but it is not likely to do very well on account of the hot weather.

For market purposes, the plants are started in the greenhouse in February, and planted out of doors as soon as the weather will permit. A large industry has developed, also, in forcing lettuce under glass at all times of the year, so that fresh lettuce can always be obtained.

88. **Celery.** — Celery is cultivated for the leaf stalks (*petioles*), which are blanched and made tender. It is poorly grown if it is greenish and tough. Celery belongs to the parsley family (Umbelliferæ), and its well-known associates were enumerated in connection with the account of parsnips and carrots (p. 376).

This vegetable is in such extensive use and requires such special treatment that it has come to be cultivated as a field crop rather than as a home garden crop. For its best development it requires a special soil, really a bog soil, but it can be grown well on clay or even sandy soils if they are enriched and irrigated. Although this is a market garden crop rather than a home garden crop, the use of celery is so universal that some information as to its culture seems desirable.

The seeds are sown in special frames of various kinds, and germination is a slow process, the seedlings being ready to transplant in about three months. For the early crop in the northern states, therefore, the seeds are started in January; and for the late crop they are started in March. The seeds are broadcast, and the young seedlings are transplanted to

other frames and spaced two to three inches apart. As soon as a new set of roots and leaves are put out, the plants are set out in the field about six inches apart in rows three to four feet apart.

For blanching the early plants boards are used, which are set up on edge beside the rows, brought together at the top, and held by cleats. Late celery is blanched by banking the earth against the plants, the banking being heightened two or three times.

Another common vegetable cultivated for its petioles is rhubarb, which belongs to the buckwheat family (Polygonaceæ), and has various "docks" for its near relatives.

Fruit

89. **Tomato.** — The tomato is a native of tropical America, and this at once suggests that it is sensitive to frost and needs warm and sunny soil and a long season. The fruit, which we use as a vegetable, is really a berry, like currants and gooseberries. The fruit was once called "love-apple" and was thought to be poisonous, but now it is very extensively cultivated, and in North America, where it is grown more extensively than in any other country, it has reached its highest degree of perfection in desirable varieties. In the United States it is grown more extensively for canning than any other vegetable, a recent report stating that over 130 million cans are packed each year, representing the cultivation of 300,000 acres. The leading states in tomato-production for canning purposes are Maryland, New Jersey, Indiana, and California.

Tomato is a member of the nightshade family (Solanaceæ), and its familiar associates are enumerated in connection with the account of the potato (p. 370).

Since the plants are very sensitive to frost, they are started in hotbeds and transplanted as soon as the danger of frost has passed. The plants are set four to five feet apart each way, and in garden-cultivation they are usually "trained" to keep

the fruit off the ground, thus securing more rapid ripening and larger and better-colored fruit. The best method of training is to support a single stem by a stake, but this is troublesome when many plants are grown. The same general results may be secured by allowing the plants to grow over an inclined rack or trellis.

90. **The gourd family.** — This is a notable family (Cucurbitaceæ) for containing numerous useful forms, whose fruits are used either as fruits or vegetables, but usage has included them all among vegetables. One genus furnishes the cucumber and muskmelon; another the watermelon; and a third the pumpkin and squash. They are all tendril-bearing herbs, with large, more or less lobed leaves, and rather large axillary flowers, which are usually yellow. The flowers are of two kinds, one (staminate) bearing the three stamens, the other (pistillate) bearing the pistil. In pumpkin, squash, and watermelon, both kinds of flowers are solitary in the axils; while in cucumber and muskmelon the staminate flowers are in clusters.

All of these forms thrive best in good soil, such as is suitable for corn and wheat; they are all sensitive to frost; and the seeds of all are planted in "hills." This method of planting is distinct from "drills" or rows, meaning the dropping of four to six (or more) seeds in a single pocket of soil, the groups of seeds being four to six feet (or even eight to ten feet) apart each way. It is also very customary to put some well-rotted manure in each hill, thus forcing the young plants into vigorous and continuous growth.

Cucumber. — The cucumber is a native of southern Asia, and has therefore been long in cultivation. It is grown both as a field crop and a garden crop, and seeds can be sown in the open as soon as danger of frost has passed, and the crop develops during the warm months.

Muskmelon. — This plant is a native of the warmer parts of Asia. This means that it is a tender plant, and an early

start in the northern states must be secured by starting seeds in hotbeds; but in the southern states they may be sown in the open field. There are two general types of muskmelon cultivated: (1) those with furrowed and thick rind, called "canteloupes"; and (2) those with netted and softer rind, called "nutmeg melons." Two notable races of nutmeg melons are the "Osage melon," developed in Michigan, and the "Rocky Ford melon," developed in Colorado. The canteloupe melons have a longer season, but the nutmeg melons are most commonly grown in the northern states in home gardens and for the early market. New Jersey is said to supply one-half the muskmelon crop; and the southern states cultivate muskmelons only for the local markets.

Watermelon. — The watermelon is a native of tropical Africa and has been very long in cultivation, but the United States now produces a larger crop than any country in the world. The watermelon develops to the greatest perfection in the soil and climate of the southern states, Georgia being particularly noted for producing the bulk of the crop shipped to the northern states and also the choicest melons. Of course in the southern states watermelons are grown as a field crop, but they can be grown readily in home gardens. The soil must be such that the plants can start quickly and grow rapidly.

Pumpkin and squash. — These coarse trailing vines grow best in corn land, and are often grown in cornfields, being planted along with the corn.

Seeds

91. **The legumes.** — Peas and beans are the chief representatives of the legume family (Leguminosæ) whose seeds are used as vegetables. Other familiar representatives of this family are enumerated in the account of forage plants (p. 362. It is evident that since peas and beans are legumes they do not impoverish soil, so far as its nitrates are concerned, but

can obtain their own nitrates with the help of soil bacteria; but this does not mean that they can do well on poor soil.

Peas. — The cultivation of peas is extremely old, the plant being a native of southern Europe and Asia, and used extensively by the most ancient races. There are numerous varieties of garden peas and field peas, but there are two types of garden peas that can be recognized easily: (1) those with smooth seeds, which are earlier and hardier varieties; and (2) those with wrinkled seeds, which are of better quality. Many of the garden varieties need poles six to eight feet high; others are not such high climbers; while still others are dwarfs and do not need stakes. The method of planting and cultivating is the same as for beans, and will be described in the next paragraph.

Beans. — There are many kinds of beans, but the ordinary beans cultivated in this country are probably natives of tropical America. The two types in ordinary cultivation are the bush beans, which are field beans, and the pole beans, which are garden beans, the latter demanding more fertile soil than the former, especially the best of all the pole beans, the Lima bean. In the cultivation of field beans, the seeds are usually planted in rows two to three feet apart, with the plants three to six inches apart in each row, and the soil is kept well stirred between the rows. In the case of pole beans, the poles are set about four feet apart each way and four or five beans planted around each pole, and the soil is cultivated frequently.

Sweet corn is also a notable seed-vegetable, which has been presented in connection with the cereals (p. 350).

CHAPTER IX

FRUITS

92. **The families.** — The majority of our cultivated fruits belong to the rose family (Rosaceæ), whose name suggests the general character of its flowers, with their more or less showy petals and numerous stamens (Fig. 62). One division of the family includes in a single genus (*Prunus*) peaches, apricots, plums, and cherries, which are "stone fruits" or "drupes." In this kind of fruit the outer part of the ovary becomes fleshy and the inner part stony, the seed being the kernel within the stone ("pit") (Fig. 63). In the case of the almond, the outer layer ripens dry instead of fleshy and splits off, freeing the large and softish stone, whose kernel (the seed) is eaten.

Another division of the family includes in a single genus (*Pyrus*) apples, pears, and quinces, whose fruits are "pomes." In this case the flesh consists of the thickened calyx tube which becomes consolidated with the ovary ("core") (Fig. 64). The edible part of the fruit, therefore, is the calyx tube, while in stone fruits it is the ovary wall.

The third and largest division of the family, to which the roses themselves belong, includes strawberries, raspberries, and blackberries. The strawberry is really a fleshy receptacle on which numerous minute pistils (the "pits") are borne (Fig. 65); while raspberries and blackberries are clusters of small fruits resembling minute stone fruits. In the raspberry the cluster of fruits slips from the receptacle like a cap (Fig. 66); while in the blackberry the cluster and the receptacle become fleshy together.

A second important fruit-bearing family is the rue family (Rutaceæ), whose genus *Citrus* includes oranges, lemons, and grape-fruits. The genus is a native of Asia, but these fruits are known everywhere. From the name of the genus, this group of fruits is usually called the "citrous fruits."

FIG. 62. — Pear, showing a branch with flowers (*A*), a section of the flower, showing how the calyx and ovary grow together to form the fruit (*B*), and a section of the fruit (*C*), showing the thickened calyx outside and the ovary or "core" within (indicated by the dotted outline). — After WOSSIDLO.

These are all really berries with a leathery rind, a berry being an ovary that becomes pulpy throughout (as currants, gooseberries, grapes, tomatoes).

A third notable fruit-bearing family is the vine family (Vitaceæ), for it includes the grapes. The habit of these woody climbers, with their tendrils, broad leaves, and clusters of small but fragrant flowers, is probably familiar to all,

for more kinds of grapes, both wild and cultivated, grow in North America than in any other country.

93. **Classification.** — The most useful classification of these fruits, for it groups them according to methods of culture, is as follows: (1) orchard or tree fruits, which are subdivided into pome fruits (apple, pear, quince), stone fruits (peach, plum, cherry), and citrous fruits (orange, lemon, grape-fruit); (2) vine fruits (grape); and (3) small fruits (strawberries, raspberries, blackberries, currants, and gooseberries).

Orchard Fruits

94. **Orchards.** — The cultivation of orchard fruits is probably most highly developed in North America. A generation ago an orchard in connection with a home was the usual thing; but now great areas are under cultivation by professional fruit-growers. In the old home orchard the trees were left to take care of themselves, so that the fruit crops were uncertain and variable, dependent upon the accident of soil and climate. Now great care is given to the soil and to the trees, and the result has been great increase in productiveness, greater uniformity, and finer quality.

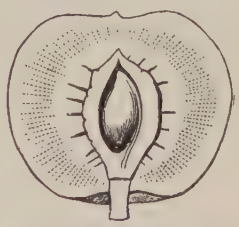


Fig. 63. — Section of a peach, showing pulp and stone formed as two layers of the ovary wall, and enclosing the seed ("kernel").—After Gray.

In establishing an orchard the soil is prepared as thoroughly as for any other crop, and for two or three years deep ploughing is practised. This puts the soil in good physical condition for retaining water, makes the soil salts more available, and assists the young trees in establishing a sufficiently extensive root system. Afterwards there is frequent light tillage early in the season; then often a cover-crop (such as clover) is sown, which is left all winter and is ploughed under in the spring.

Pruning has also come to be a fine art, and when done properly, a little every year, there is a larger yield; and when to this there is added an intelligent thinning of the developing fruit, the quality is improved.

95. **Apple.** — The apple is the most important pome fruit, having been cultivated from very ancient times. It is a native of southwestern Asia and adjacent Europe, but is now under cultivation in all countries. All of the different kinds of apples, which number about 1000 on sale in

FIG. 64. — Longitudinal and cross-sections of apple, showing the "five-celled" ovary (core) imbedded in the fleshy cup of the calyx.

any year, have been derived from two wild species, one of which has given rise to the ordinary apples, the other to the crab apples. The enormous number of varieties makes it possible to select for each area those best adapted for it, and this information is perhaps best obtained from the various state horticultural societies.

In the United States and Canada there are several notable areas of apple cultivation, and new ones are being developed rapidly. What has long been regarded as the finest apple region in productiveness, quality, and good keeping is the region extending from the Great Lakes eastward to Nova

Scotia. Other notable regions are in Virginia, in Arkansas, in various parts of the plains, and in the Pacific states. More apples are produced in North America than in any country of the world, a good crop for the United States and Canada being approximately 100,000,000 barrels.

FIG. 65. — A strawberry, being an enlarged and pulpy receptacle bearing numerous seed-like fruits sunken in small pits. — After BAILEY.

One of the reasons why the proper care of apple orchards has been so much neglected is that they thrive reasonably well almost anywhere. The best land, however, is said to be good wheat or corn land, which means a clay loam. The grafting methods by which old stocks may be used to support more desirable varieties have been described (p. 330).

96. **Pear.** — The pear is also a native of Asia and Europe, but is a much more uncertain crop than the apple. It flourishes best from the New England states to the Great Lakes, and on the Pacific slope. In the interior, the uncertainty of the pear crop arises from the prevalence of a disease called "pear blight," which blasts the branches, and which spreads so rapidly that extensive orchards may be destroyed. In the south, the climate is too warm for the best development of trees and for the best quality of fruit; while in the northern prairie states the winters are too severe.

FIG. 66. — A raspberry, showing the "cap" of small fruits removed from the receptacle. — After BAILEY.

There are many varieties, but those most common in the markets are very apt to be the various races of Bartlett, Kieffer, and Seckel pears. The pear can be grafted on

quince stock and grown as a dwarf. These "dwarf pears" reach the bearing stage earlier than the others and are more easily handled in all the necessary operations, but they require more care than do the ordinary trees.

The *quince* needs no special statement. It is an interesting and peculiar fruit, but there is no large or increasing demand for it.

97. **Peach.** — The peach is probably the most highly prized of the stone fruits. A native of Asia, its cultivation in the United States is always attended with risk. This arises from the fact that it is a very early bloomer, and being sensitive to frost, the flowers and buds are in danger of being killed by a late frost. This risk is greater in the south than in the north, because the buds swell earlier.

On account of this danger from freezing, the commercial areas of peach cultivation are near large bodies of water, where the winter temperature is milder, as near the seacoast, far enough inland to escape strong winds, and near the Great Lakes. Of course peaches are grown over a great range of country, the failures probably being as frequent as the successes, but the commercial regions are not numerous.

The peach orchards along the southern borders of the Great Lakes extend along Lake Ontario in New York and Canada, along Lake Erie in Ohio, and along the eastern shore of Lake Michigan. It is in the "Michigan fruit belt" that the peach reaches its northern limit in the eastern states.

Another large area extends from Connecticut, near Long Island Sound, southward to Cape Charles (Virginia), the "Delaware peaches" holding the same important position in the eastern market that the "Michigan peaches" do in the western.

Other peach areas are in northern Georgia and Alabama and adjacent states; from southern Illinois westward into Kansas; in western Colorado; and throughout California, except in the mountains.

As may be inferred from the regions of most successful peach-cultivation, a light and sandy soil is the best, being quite in contrast with the best soil for pome fruits. Peaches are propagated by seeds, and then on the seedlings of the first year the desired varieties are budded. The tilling and other care of a peach orchard can never be neglected.

98. **Plum.** — There are native plums in all countries, and numerous species are in cultivation. Since they are so variable in origin, they are not equally adapted to all regions. The European type is the plum of history and is cultivated in the northeastern states and on the Pacific slope. It has produced the more familiar old races, such as the Green Gage, Damson, etc., and is the chief source of prunes. In the same regions, and also in parts of the interior and in the south, the Japanese plums are gaining recognition. In the colder northern regions and over the larger part of the interior basin our own native plums are cultivated. There are hundreds of varieties, no less than 300 varieties having been derived from six native American species.

In propagation, grafting and budding are practised as usual; but to secure desirable varieties not adapted to the soil conditions of a region, it is customary to grow stock plants for soil conditions and graft scions upon them for the fruit.

Prunes are plums that dry sweet without removing the pits. In other plums there is a fermentation or "souring" about the pit as the plum dries. In California, prunes form the most important plum product, 6,000,000 trees (55,000 acres) being reported in 1900, seven-eighths of which were used for prune-production.

99. **Apricot.** — This fruit, intermediate between peach and plum, is a native of the China-Japan region, and is grown commercially in New York and other eastern states, and also in California. Its importance in California may be indicated by the fact that in 1900 there were 3,000,000

trees (40,000 acres) in cultivation, and the acreage was rapidly increasing. The danger from frost is the same as for peaches, but the interior valleys of California furnish a most congenial situation.

100. **Cherry.** — The cherry is of European origin, and the various cultivated races are grouped as sour cherries and sweet cherries. The sour cherries are cultivated in orchards for canning purposes in a number of states, extending from New York and New Jersey to Kansas and Nebraska. The sweet cherries are restricted mostly to what is called "door-yard" planting. In California, cherries are the least commercially important of the temperate fruits, but they attain unusual size. Cherry trees are grafted with unusual readiness, so that large orchards can be transformed into more desirable varieties.

101. **Orange.** — This is the best known of the table citrous fruits, and is one of the oldest of cultivated fruits. In fact, it has been so long in cultivation that its native region is in doubt, although probably it has come from southern and eastern Asia. Now it is grown in all warm temperate and tropical countries.

The structure of an orange is familiar to every one, but certain variations should be noted. Ordinarily an orange contains ten compartments, but the number is often increased through cultivation; and in some cases a secondary axis with its small compartments is developed in the center of the fruit, forming the "navel" orange. The best-known navel orange is the "Washington navel," which started as a chance seedling brought from Brazil in 1870. This navel orange is also seedless.

There are three well-developed orange regions in the United States: (1) central and southern Florida, (2) the delta region of the Mississippi, and (3) California. Formerly most of our oranges were imported from the Mediterranean region, but these were replaced for the most part by Florida

oranges. In the winter of 1894–1895, however, there occurred the "great freeze" in Florida, and since that time California oranges have become better known. Some appreciation of the destruction wrought by the great freeze may be obtained from the statement that in the season of the freeze the orange crop of Florida had reached its maximum, 6,000,000 boxes, while in the next year there were only 100,000 boxes; in 1900 the crop reached 1,000,000 boxes. In California, in 1900, there were 3,500,000 trees in cultivation (nearly one-half of them bearing), which yielded 4,000,000 boxes or more. In 1911 the citrous crop of California reached a total of 14,000,000 boxes.

102. **Lemon.** — This is one of our most important commercial fruits, and is cultivated extensively in all tropical and subtropical regions, being less hardy than the orange. In our country, lemon culture is practically restricted to Florida and California, and large quantities of lemons are imported, chiefly from Italy and Sicily. Lemon culture in Florida was almost annihilated by the cold winter of 1894–1895, when nearly all the trees were killed, leaving only a few isolated orchards which recovered. Since that time, more attention has been given to other fruits.

In California, although the lemon has been grown for a long time, its commercial importance has increased only in comparatively recent times. In 1900 there were 250,000 bearing trees and a million more in cultivation. The prominence of California lemons has come from the fact that the old thick-skinned, bitter, and rather juiceless type has been replaced by types having the thin rind, freedom from bitterness, and abundance of citric acid characteristic of the lemons of the Mediterranean region.

103. **Grape-fruit.** — This citrous fruit has come into great prominence, and there have been many misconceptions as to its origin. It is a native of the Malayan and Polynesian Islands and its real name is "pomelo," a name which means

literally " melon apple." When it came into cultivation in Jamaica it was called " grape-fruit " because the fruit is borne in clusters of three to fifteen, like a cluster of huge grapes. It has also been called " fruit of Paradise " and " forbidden fruit," and the pear-shaped varieties, which now seldom appear in market, are called " shaddocks."

Grape-fruits are cultivated extensively in India, the West Indies, Florida, and California, but most of the cultivated varieties have been developed in Florida, where it is grown to greatest perfection. Its commercial cultivation extended from Florida to Jamaica and California. The grape-fruit is cultivated like the orange, but it is more sensitive to cold, and in the destructive winter of 1894–1895 all the trees were killed in northern and central Florida.

Vine Fruits

104. **Grape.** — The grape is probably the oldest fruit in cultivation, and its chief use has been the manufacture of wine. The grape of history is *Vitis vinifera* (the specific name means " wine-bearing "), and it is probably of Asiatic origin. Although the chief use of grapes is to manufacture wine, a secondary use is the production of raisins, and in the United States there has been developed a notable series of " table grapes."

The grape in this country has had a most interesting history. The early settlers naturally tried to introduce the European *Vitis vinifera*, but after persistent effort its cultivation had to be abandoned on account of a destructive disease that attacked it. Then attention was given to the possibilities of the native American grapes, of which there are numerous species. A species of the Atlantic coast region (*Vitis Labrusca*) has been most developed, and its cultivated varieties were produced to eat rather than to drink. Among them are such well-known grapes as the Concord and Catawba. The United States is responsible,

therefore, for the development of the highest types of table grapes. In addition to the native species that have been brought under cultivation, from which 800 named varieties have been produced, there are numerous other promising species that await development. While table grapes were being developed in the eastern states, the Old World *Vitis vinifera* was being established in California, where it was free from the disease which attacked it in the eastern states. In California, therefore, grape culture is like that in Europe, and wine is the principal product.

Although grapes are cultivated almost everywhere in the United States, the area of commercial grape culture is not very extensive. The greatest areas in the eastern states are those in New York and Ohio bordering lakes and large streams, as the lower part of the Hudson River valley, the lake region of central and western New York, and the Lake Erie region of New York, Pennsylvania, and Ohio. There are also large vineyards in Ontario, Michigan, etc., and grape culture is extending into other regions. The area of grape culture in California in 1900 was 140,000 acres, one-seventh of the product being table grapes, two-sevenths raisin grapes, and four-sevenths wine grapes.

The care of grape-vines requires knowledge and experience, for proper pruning, to reduce the amount of wood and to keep the plant in suitable form, can be learned only by demonstration. The training of the vines is to keep them off the ground, so that the fruit may be exposed to light and air. Naturally in extensive cultivation this training is of the simplest sort to secure the result; but in home cultivation it often takes the form of a more or less elaborate "grape arbor." The propagation of grapes is usually by cuttings, already described (p. 326), which are usually secured in the winter from the trimmings of vineyards. These cuttings, each one with two or three buds, are usually kept until spring by being buried half their depth in sand in a cellar.

Small Fruits

105. **Strawberry.** — There are wild strawberries in the eastern states, and a generation or two ago strawberries were scarcely known except in the wild state, but these wild species have not yielded much to cultivation. All of the common cultivated forms are derived from a Pacific coast species which was introduced into cultivation over 200 years ago from Chili. It is now possible for any one who has a plot of ground to have a strawberry bed.

The strawberry plant is propagated naturally by runners, which form after blossoming. A runner strikes root at the tip and sends up a cluster of leaves, thus establishing an independent plant (Fig. 67). In cultivation, these runner plants are transplanted or let alone, and they bear fruit the following year. A strawberry bed may bear for several years, but the first and second crops are the best, so that it is customary to break up a bed after one to three years of bearing.

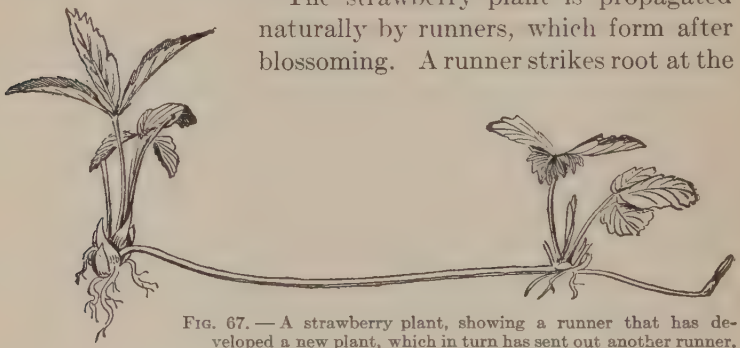


FIG. 67. — A strawberry plant, showing a runner that has developed a new plant, which in turn has sent out another runner. — After SEUBERT.

The best soil is a dark, sandy, and rather moist loam, and good drainage is necessary. In preparing a bed the soil is top-dressed with fine manure and well pulverized. Then the plants are set out, obtained from the runner plants of the previous season. These young plants are usually better allowed to remain in connection with the parent plants until

spring and then transplanted, and of course runner plants that have not borne fruit are the best. To secure the best berries, each plant should have a space to itself ("hill"), which can be cultivated all around. The old way of allowing beds to become matted with runners is passing out, for many berries are covered up and in a very unfavorable position for development. Therefore, when a large area is under cultivation, and liberal hills are impracticable, narrow and rather close rows are used, so that as much fruit as possible may be "on the outside." In the fall it is usual to mulch the beds to protect them through the winter and early spring. This mulch is a covering of clean straw or material containing straw. In the south, pine needles are used, while near the sea-coast salt marsh hay is convenient.

The growth of strawberry plants is during the cool season of the year, and of course in the south this means very early in the year. In fact the cultivated berries seem to find their most congenial home in the south, where they are the most important of the small fruits.

106. **Raspberry.** — Raspberries are brambles, associated in the same genus (*Rubus*) with blackberries, from which they differ in the fact that the close cluster of small fruits separates from the receptacle like a cap. The European species (*Rubus Idæus*) has been longest in cultivation, and has yielded many important varieties of high quality, but it lacks hardiness and productiveness in the United States, and for this reason it is our least important species.

It is from American species that we have obtained our commonly cultivated red and black raspberries. *Rubus strigosus* is a red raspberry, like its European relative. Perhaps it is inferior in quality, but it is more hardy and productive, and therefore almost all the red raspberries of the market are from this American species. *Rubus occidentalis* is the black raspberry, or "black cap," and its races, although they are perhaps less liked by most people than the reds, are

our most important commercial raspberries, for they are easily cultivated, are hardy and productive, and are better for market handling. The black raspberries are propagated by cuttings obtained by layering, a process already described (p. 329); while red raspberries develop numerous suckers from the roots which are often used as cuttings.

107. **Currant and gooseberry.** — These are two of our hardiest bush fruits, that are propagated by cuttings, layering, and root cuttings. They are more intensively cultivated in England than in the United States, the English gooseberries being highly cultivated and used as a table fruit in a way that is impossible with their American relatives.

108. **Suggestions for work.** — The fruits mentioned in this chapter are in such common use and so easily recognized that there is no need for exercises in distinguishing them, but there are four useful things that should be done if possible.

1. The various fruits should be sectioned and their structure examined, noting the variations that occur, especially in the amount of fruit pulp.

2. The home markets should be visited and inquiries made as to the sources of the fruit displayed. This will develop some knowledge of the regions from which various fruits come at different seasons, and will also fix the seasons when the different fruits may be expected and when they are at their best

3. The names of the most common varieties should be learned. For example, the prominent apples and pears should be known by name and recognized at sight.

4. If the neighborhood permits it, orchards, and even dooryards and gardens, should be visited to see the various fruit-bearing plants in cultivation. This will fix in mind the general habit of the plants, their appearance in cultivation, and will probably enable the student to contrast proper and improper methods of cultivation.

CHAPTER X

FLOWERS

109. **Floriculture.** — The cultivation of flowers for ornament and of ornamental plants is called *floriculture*. The use of plants for this purpose has brought into cultivation a very large number of species; in fact, floriculture has drawn upon the whole of the immense group of flowering plants (Angiosperms), and has selected for its work whatever is beautiful or curious. It is evident that it will be impossible to give an account of even the most common flowers and ornamental plants in cultivation, but some general idea can be given of the work of floriculture. Plants are in more general cultivation for their flowers than for any other purpose. The public parks are full of them, almost every yard has its flower bed, and in the absence of yards "window-gardens" are established. The cultivation of such plants, therefore, touches the experience of more people than any other kind of cultivation; besides, it is just as possible in cities as in the country.

Floriculture is not merely the cultivation of ornamental plants by people in general, but it has also developed into an extensive business, conducted by "florists," and the work is done chiefly in greenhouses. The demand for flowers, and especially "cut flowers," has been increasing at such a rate that special equipment for forcing flowers and distributing them has been developed. Naturally the largest establishments are near the large cities, where the demand is greatest, and the cities which are now leading in this business are New York, Chicago, Boston, and Philadelphia. The greatest amount of greenhouse space used for horticul-

ture is found in New York, Illinois, Pennsylvania, and New Jersey, in the order named. It is reported that about $25,000,000 are expended for flowers each year, about half of it for cut flowers and the other half for plants.

The most important commercial flower grown is the rose, the annual sale being at least $6,000,000, which represents about one billion flowers. The second flower in importance is the carnation, the annual sale being about $4,000,000; while the violet is the third.

A brief account will be given of the cultivation of a few representative flowers, and they will serve to illustrate the cultivation of flowers in general.

110. **Production of new forms.** — Great attention is given by florists to the production of new forms of flowers which may attract attention. Every year new forms of roses, carnations, chrysanthemums, etc., are announced. Some of these variations are obtained by detecting a chance variation or "sport" occurring among the ordinary plants. Far the greater number, however, are deliberately worked for by hybridizing (p. 338). Two forms are selected and artificial pollination is secured. The hybrid progeny from the seeds are examined in the hope that one or more individuals may show desirable characters, either new characters or a new combination of characters, and these are propagated. Repeated crosses may be made, several varieties being used and hybrids being crossed again, until often very complex mixtures are obtained. It is evident that by making crosses repeatedly and in every direction, a reasonable number of attractive combinations are obtained. It is like stirring up all sorts of food ingredients in all sorts of proportions, in the hope that some one of the mixtures will prove to be a palatable dish. While this method of securing new forms seems to be largely a matter of chance, if a sufficiently large number of hybrid forms is produced, the chance of securing a desirable form becomes a practical certainty.

It must not be supposed that miscellaneous mixtures are the only ones used by florists. Often the mixtures are definite and have in view a combination of desirable characters that exist separately in the two parents. For example, it is very common to work for such a combination as color and size of flower, by crossing flowers of the desired color with flowers of the desired size. In this way, for example, many new carnations and chrysanthemums are produced. Often it is desired merely to increase the size of a desirable flower beyond its usual limit, and this can usually be secured by the selection and propagation of the largest flowers through a series of generations. This has resulted in the production of some remarkably large chrysanthemums and carnations.

One of the best illustrations of crossing to secure definite results is the Shasta daisy produced by Luther Burbank. It is a triple hybrid, that is, it is a mixture of three forms, each one contributing certain features. The American form, common throughout the east as a weed, is known as oxeye daisy or marguerite. It is an abundant bloomer, but the habit of the plant is not handsome, being rather loose and straggling. The English representative has a handsome habit, with tall and stiff stems; while the Japanese form is characterized by the pearly luster of the flowers. By crossing these three forms, the Shasta daisy was produced, which combines in a single individual the profuse blooming of the American form, the erect habit of the English form, and the pearly white flowers of the Japanese form.

111. **Rose.** — The varieties of roses (Fig. 68) are so numerous and the methods of handling them are so varied that no general account can cover them. The situation may be illustrated, however, by taking the case of a home rose garden, which any one can secure who controls a small plot of ground.

The spot selected must be sunny, but protected against

the worst winds, as by a fence or hedge. As a well-known writer has said, "the rose garden must have shelter, but it must not have shade." The best results are secured with good garden soil, but a rose bed can be made good if the original soil is bad, the chief thing to provide for in such a case being a deep bed and good drainage, for roses do not tolerate free water in the soil. Roses are propagated by seeds, cuttings, grafting, and budding, but those who are preparing a small rose garden will probably use cuttings or started plants obtained from a florist or from a neighbor. These cuttings are best planted late in autumn, about 30 inches apart, and the soil protected, preferably with stable manure. In the spring the bed should receive shallow tillage, and then the surface should be raked at intervals.

FIG. 68. — A rose. — After BAILEY.

Cultivated roses are roughly grouped into two kinds: those that bloom only once (in summer) and those that bloom more or less continuously. The varieties are so numerous, however, and differ so much as to hardiness and adaptation to different regions, that advice as to the selection of the proper forms to cultivate must be obtained from those who have had experience.

112. **Carnation.** — Carnations (Fig. 69) belong to the pink family (Caryophyllaceæ), and are associated in the same genus (*Dianthus*) with the old-fashioned and fragrant "pinks" once found in every home garden. The cultivated carnations are derived from a European species (*Dianthus Caryophyllus*), which has been cultivated from very early times. The name "carnation" was applied to the plant

on account of its flesh-colored flowers, but the color of the flower in its wild state has been broken up into a great variety of colors in the cultivated races. It may be of interest to know that the old English name for carnation was "gillyflower," a name that appears often in English literature.

The older cultivated races of carnations have practically disappeared, and have been replaced by new ones that flower more or less continuously and are especially adapted for forcing, so that carnations can be obtained at any season of the year. It is reported that about 500 varieties of carnation have been produced in the United States, where the carnation industry is better developed than in any other country.

Fig. 69.—A carnation.

Of course carnations can be grown from the seed, but florists use this method only when they are desirous of securing variations that may be useful. In general, they are propagated by cuttings, which may seem strange for an herb. Carnations are not very suitable for ordinary garden cultivation, but no one will regret the cultivation of a few "pinks" with their clove-like fragrance.

113. **Violet.** — It has been stated that violet culture is third in commercial importance among cultivated flowers. The numerous commercial violets are derived from the European *Viola odorata*, and their successful cultivation requires an amount of intelligent care that can be given only by the specialist.

If the violets of the florists are not suitable for home culture, another violet, the pansy, is always suitable, for it is very easy to cultivate (Fig. 70). The pansies are derived from another European species, *Viola tricolor*, the name re-

ferring to the characteristic variegated colors of the flower. The old English name of the pansy is "heart's-ease," and it has always been a favorite home-garden flower. Numerous garden varieties have been developed, that differ as to size of flower, nature of coloring, and arrangement of colors. The highly developed varieties are not apt to continue true in unskilled hands, so that the safest plan is to secure seed from the breeder each year.

FIG. 70. — Pansies.

The plot selected for the cultivation of pansies should be sheltered from wind and exposed to the morning sun if possible, and good garden soil will produce the best pansies. For early spring blooming, the seed is sown in August, the bed is covered with strawy manure and kept moist. In about two weeks the plants will appear and the straw is gradually removed. In the next spring the flowers will appear. To secure blooming during the late summer and autumn, seeds can be germinated within doors from February to June, and the young plants set out into the permanent bed.

FIG. 71. — Sweet peas.

114. **Sweet pea.** — Sweet peas (Fig. 71), as the name suggests, belong to the legume family (Leguminosæ), along with garden peas and beans. The originals of the cultivated varieties came from the Mediterranean region and southern Asia, and the number of shades of color now represented by the 200 varieties is surprising. The supply of seed for the world

is produced principally in California, and on this account a large number of new forms have been secured in America.

Although the cultivation of fancy strains has been made a matter of competition, the sweet pea is still a home-garden plant and is usually one of the few selected for planting. Garden soil is needed, but it must be remembered that too much enriching will result in a vigorous vine at the expense of flowers. The soil is prepared in the autumn, and the seeds are planted as soon as the frost is out of the ground. The seeds are placed in rows and covered so that a little furrow is left for the retention of moisture. Germination and early growth should be allowed to proceed slowly, and very superficial tilling should be employed. The usual garden varieties need a firm support of some kind, about six feet high; but there are bush varieties that require no support; and also low varieties that spread compactly over the ground.

Fig. 72. — A chrysanthemum.

115. **Chrysanthemum.** — This is not an ordinary home-garden plant (Fig. 72), but it is so familiar a flower and has had such an interesting history that some information in reference to it is not out of place. It belongs to the composite family (Compositæ), the ranking family of flowering plants, associated with golden-rods, asters, sunflowers, dahlias, dandelions, etc., its so-called flower being a compact head of small flowers surrounded by leafy bracts (involucre), as described under lettuce (p. 380).

The cultivated chrysanthemum holds the same conspicuous position among the cultivated flowers of the orient that the rose holds in the occident, the original forms growing as natives in China and Japan. There are very many types in cultivation, but those ordinarily exhibited have large and

"doubled" flowers of various colors, with the flowers sometimes in a compact ball, at other times more loosely disposed. It is said that the chrysanthemum stands fourth in the list of commercial flowers in the United States, although its season is only about six weeks long.

116. **Narcissus.** — This is a genus of the amaryllis family, which includes some of the most attractive of the very early home-garden flowers. They are known in general as daffodils and jonquils, and are familiar to every one. The flowers are characterized by having a "crown" arising from the top of the tubular, six-lobed perianth. The daffodils have large yellow flowers, with a crown as long as the lobes of the flower or longer and with a more or less crisped margin (Fig. 73); while the jonquils have small yellow and fragrant flowers, with a crown less than half the length of the flower lobes. The "poet's Narcissus," often cultivated and seen at florists, is like the jonquil, except that the fragrant flowers are white and the short crown is edged with pink.

FIG. 73. — A daffodil.

These plants are hardy and easily cared for, so that no garden should be without them. They thrive in good soil, and they develop so early that moisture is usually plentiful. About the only caution necessary is to be careful that no manure touches the bulbs. The bulbs are planted, late in summer or early in the autumn, six to eight inches deep and three inches apart, and remain until strong groups are formed. These groups can occupy the same place for a series of years, and early each spring the flowers begin to appear. These narcissus forms are also especially adapted for house plants,

three or more bulbs being set in a pot, with the necks of the bulbs at the surface of the soil. A succession of plantings in pots will yield a succession of flowers throughout the winter.

117. **Tulip.** — The tulips are natives of the oriental countries and belong to the lily family (Liliaceæ). The origin of the common garden tulips (Fig. 74) is unknown, for they had been long under cultivation by the Turks before they came under the observation of other nations. The tulip has a curious connection with the history of Holland, for its introduction into that country resulted in the so-called "tulip-craze" of the seventeenth century, a craze which compelled the interference of the government. Holland is still the center of the development of tulip bulbs.

Fig. 74. — A tulip.

The tulips, like the daffodils and jonquils, are early bloomers, and adapted to cultivation in home gardens. The bulbs are set out in the autumn, before severe freezing, in sandy loam which is best enriched by leaf-mould and well drained. The bulbs are planted about four inches deep and four to five inches apart, and when the ground begins to freeze the bed should be covered with leaves or other light material. In the spring, when severe cold is over, the beds are uncovered, and the plants will probably require no further attention. In the selection of bulbs, it should be known that the size of the bulb is not so important as an abundance of fibrous roots.

118. **Aster.** — Asters are introduced here because they are late bloomers, and belong to the end of the season, as tulips, daffodils, and jonquils belong to the beginning of the season. Asters belong to the composite family, along with the chrysanthemum, and they are especially abundant as

native plants in North America. The commonly cultivated aster (Fig. 75), however, is not an aster, but is a near relative, whose fuller name is "China aster." As the name suggests, it is a native of China, and is perhaps the favorite fall-blooming flower. It has been developed into "double" forms of various kinds, such as the chrysanthemum, and its original blue has been extended into a series of colors, including red, pink, and purple.

The seeds are sown early in spring, in a well-tilled bed, in shallow rows and covered with fine dirt. When the plants appear, they are thinned out as necessary, and the soil is cared for by the usual tilling to retain moisture in dry weather. A bed of fall-blooming asters in the late autumn, when all other flowers are gone, well repays the little care it involves.

FIG. 75. — China asters. — After BAILEY.

119. **Suggestions for work.** — The very few flowers described in this chapter are intended to be only samples of the more commonly seen flowers, and the list should be much extended by observing the various flowers in common cultivation in the neighborhood, both in home gardens, and by florists. A visit to some florist's establishment will give some idea of the kinds of flowers that are being cultivated for the market at a given time.

In addition to these observations of flowers in cultivation, some of the more rapidly growing forms should be propagated as a part of the laboratory work, and other representative forms should be brought from the florist's in pots, and not only observed, but also cared for.

CHAPTER XI

FIBER PLANTS

120. **General statement.** — While fiber plants cannot be included among those of common cultivation, they cannot be excluded from any account of important plants cultivated by man. Moreover, some of them are of such great importance that every student of plants in cultivation should know something about them. There are hundreds of plants whose fibers might be used, but thirty or forty species at present supply the plant fibers of commerce.

The most conspicuous are cotton and flax, the latter being used in the manufacture of linen. After these come the various hemps used for ropes, and the fibers used for matting. A brief account will be given of the origin and production of these most important fibers, and it will be easy to secure specimens of the "raw" fibers, showing how they appear when connected with their plants.

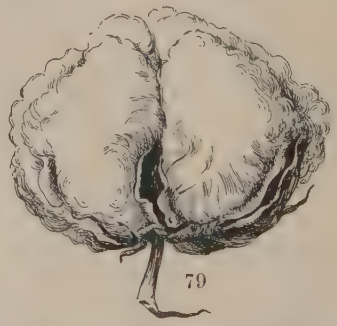
FIG. 76. — Branch of cotton plant, showing foliage and flowers. — After WOSSIDLO.

121. **Cotton.** — The cotton plant is said to be grown over a greater area, by a greater number of people, and is useful for more purposes than any other fiber plant. Not only is its fiber exceedingly important, but its seeds yield important products, among which "cotton-seed oil" is coming to be generally known.

Cotton is a member of the mallow family (Malvaceæ), which is characterized chiefly by the fact that its numerous stamens grow together to form a tube that surrounds the pistil (Figs. 76 and 77). Associated with cotton in this family are such familiar plants as hollyhock, the mallows, abutilon, hibiscus, etc. The cotton genus (*Gossypium*) has numerous species, but only a few of them are cultivated for the fiber. The fiber occurs on the seeds in a fluffy, woolly mass (Fig. 78), and the seed-vessel is called the "boll" (really the fruit of the cotton plant). It is easy to obtain samples of these bolls, which burst open and allow the mass of fibers to emerge (Fig. 79).

FIG. 77. — Section of a cotton flower, showing the large petals and the tube formed by the stamens. — After BAILLON.

78



79

FIGS. 78 and 79. — Fiber of cotton: fig. 78, section of seed with fibers attached (after BAILLON); fig. 79, a cotton boll, burst and showing the mass of fibers (after BAILEY).

The value of the fiber is due to the fact that it has a twist that makes it extremely well adapted for spinning.

The various kinds of cotton differ in the quality and

length of the fibers, the most highly prized being the Sea Island cotton, with its long and silky fibers. This cotton grows to the greatest perfection along the coast regions of South Carolina, Georgia, and Florida. There is also "upland" cotton grown in the United States, whose fibers are shorter than those of the Sea Island cotton, but which can be cultivated over a much more extensive area than the finer cotton. In the market the various cottons are graded according to the length of the fibers.

It is well known to every school boy and girl that a new epoch in the production of cotton was introduced by Whitney's invention of the cotton gin in 1793; and from that time the production of cotton in the United States has been an increasing industry in the southern states. In 1860 the United States furnished 79 per cent of the cotton used in Europe, but during the Civil War it dropped to a little over 3 per cent; in 1900 it had risen again to 80 per cent. In 1911 the total cotton production of the United States was 14,775,000 bales, while the estimated production for 1912 was 13,000,000 bales. A standard bale weighs 500 pounds.

It is interesting to compare the production of cotton in the various countries of the world, and also to compare its production in the various southern states. The total production of cotton in the world cannot be known, since a large amount is produced and used in countries where no records are kept. The following figures, therefore, deal only with those countries from which information can be obtained which is either exact or approximate. Taking only such countries into the count, the world's production of cotton in 1910 was about 20,000,000 bales. The comparison of cotton-producing countries in 1910 is as follows, the figures indicating the number of bales: United States 11,608,000, India 3,874,000, Egypt 1,570,000, China 1,200,000, Russia 688,000, Brazil 270,000, Mexico 200,000, Turkey 141,000, Persia 128,000, Peru 115,000.

In comparing the production of cotton by states, it is interesting to note the changes during ten years. In 1900 the record of the principal cotton-growing states, in the order of production, the numbers indicating bales of 500 pounds, was approximately as follows: Texas 2,610,000, Mississippi 1,240,000, Georgia 1,230,000, Alabama 1,000,000, South Carolina 840,000, Arkansas 705,000, Louisiana 700,000, North Carolina 440,000, Tennessee

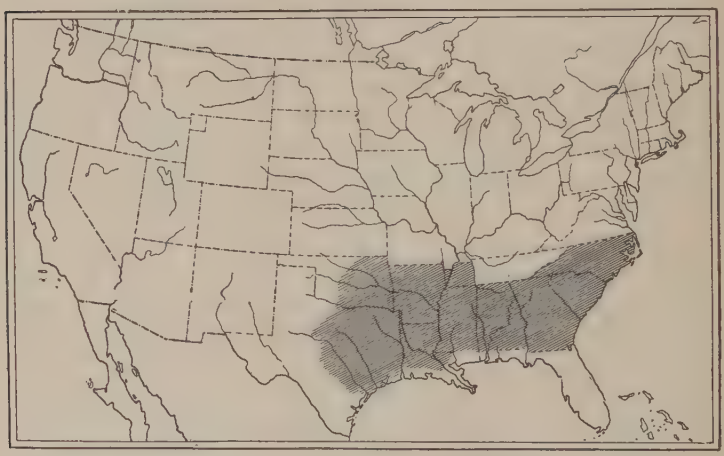


Fig. 80. — Map shaded to show the states of greatest cotton-production.

210,000, Indian Territory 145,000, Oklahoma 70,000, Florida 50,000; all other states nearly 30,000. In 1911, when the total production was approximately 15,000,000 bales, the seven principal states were as follows: Texas 4,200,000, Georgia 2,770,000, Alabama 1,700,000, South Carolina 1,650,000, Mississippi 1,200,000, North Carolina 1,100,000, Oklahoma 1,000,000, all other states about 1,400,000 (Fig. 80).

122. **Flax.** — There are numerous species of flax, but the common form in cultivation is a native of the Mediterranean

region. It belongs to a small family (Linaceæ), which received its name from the flax genus (*Linum*). The name of the common flax is *Linum usitatissimum*, which means "most useful flax." It is a low herb, with narrow leaves and handsome blue flowers (Fig. 81).

It is cultivated for the fibers of its stem and also for its seeds. The fibers are long, fine, and very strong, so that it can be spun into very stout thread (linen thread) and woven into very durable cloth (linen). This fiber is also used when especially strong twine or rope or sails are needed. Every one is familiar with the strong body of oil-cloth, which is woven of flax fiber. The seeds yield the well-known linseed oil, used for mixing paints and varnishes, and in various other ways.

Fig. 81. — A flax plant.

This very useful plant has been cultivated from the earliest times, but now its most extensive cultivation in Europe is in Russia, Belgium, and Ireland. In the United States it has been cultivated for its seed ever since the first settlements, but lately it has attracted attention as a fiber plant, especially in Michigan, Wisconsin, Minnesota, North Dakota, and Washington.

The world's production of flaxseed in 1898 was about 76,000,000 bushels, Europe producing 31,000,000 bushels, America 27,000,000 bushels, and India 18,000,000 bushels. In the same year the production of fiber was about 1,800,000 pounds, all of which is credited to Europe. About ten years later, in 1909, the world's production of flaxseed amounted to 101,000,000 bushels; and in 1912 the United States produced about 28,000,000 bushels.

Russia leads all countries in the production of both seed and fiber, but the Belgian flax is the best, due to the great care taken in its cultivation. Flax demands greater labor than almost any crop, and its value for fiber is in proportion to the amount of intelligent care it receives. For fine fiber the seeds are sown thickly, so that the plants are crowded, and the young plants are pulled before the seeds are mature. For coarse fiber, the plants are given more room and pulled when the seeds are nearly mature. Usually the plants are pulled up by hand, roots and all, and the processes used for separating the fibers from the rest of the tissues need care and labor. Flax is said to exhaust the soil more than any other crop, so that much attention must be given to keeping the soil in proper condition.

Fig. 82. — A hemp plant. — After Internat. Encycl.

123. **Hemp.** — Fibers from a great many plants are called hemp, but the common hemp, cultivated from the earliest times, belongs to the nettle family (Urticaceæ). Its name is *Cannabis sativa*, and it is a native of the warmer parts of Asia, but it has become naturalized in Europe and America. It is a rough herb, with palmately compound leaves (Fig. 82), and two kinds of flowers borne on different plants (*diœcious*). The staminate flowers are in open clusters, while the pistillate flowers are in compact clusters like a spike. The hemp plant has some strange associates in the nettle family. It is closely allied to hops, but in another

section of the family are the elms, and in still another section are the figs, mulberries, and nettles.

Hemp is cultivated for its fiber in all the countries of Europe, but its most extensive production is in central and southern Russia, which supplies the largest part of the world's hemp. In the United States it is cultivated to some extent, especially in Kentucky, Missouri, and Illinois; but its production in this country has been greatly reduced by the introduction of Manila hemp.

The fiber is used for coarser purposes than flax fiber, such as for ordinary ropes, for calking of vessels, etc. The seed is also produced in great abundance as "bird seed" for cage birds.

The name "hemp" has been applied to the fibers of other plants which are used for the same purposes, the most conspicuous of which are "bowstring hemp," "Manila hemp," "Sisal hemp," and "Sunn hemp." These will serve to illustrate the variety of plants whose fiber can be used in this way.

Bowstring hemp received its name from its use in making bowstrings. The plant belongs to the lily family and is native in the tropical jungles of both eastern and western hemispheres.

Manila hemp is from a species of banana growing in the Philippines, where it is extensively cultivated. It is a very strong fiber and has come to be used in the United States for binding twine and cordage.

Sisal hemp is from an agave growing in Mexico, Yucatan, and the West Indies, and has been introduced into the Bahamas and Florida. It is second only to Manila hemp in strength.

Sunn hemp is from a member of the legume family growing in India. It is not as strong a fiber as the other hemps mentioned above, but it makes fairly good ropes, canvas, etc.

124. **Suggestions for work.** — Cotton "bolls" should be obtained, and the character of the fibers and their relation to the seeds examined. It should not be difficult, also, to obtain samples of various kinds of cotton fiber, "staples," as they are called. Flaxseed can be obtained in any drug store, and young flax plants can be grown and their fibrous character observed. Wild hemp may be growing in the neighborhood as a weed, and should be investigated.

CHAPTER XII

FORESTRY

125. **Definition.** — Forestry includes so many things that it is a difficult word to define. Primarily it means the care of forests, but it has often come to include also the care of individual trees. Both of these aspects will be considered here.

A forest is often called "woods" in America, and the area covered varies from many miles in extent to the small "wood-lots" that remain in connection with many homesteads. The method of caring is the same whether a forest is large or small. The abuse of forests in this country is well known, but this is the common experience of new countries. The time has now come when we have begun to realize the necessity of caring for our forests, and among the "conservation" movements, the conservation of forests holds a very important place. Forestry is an application of scientific knowledge, chiefly botanical, but including other sciences as well. Some indication of the many things a forester must consider will help to an understanding of his profession.

Forestry includes not only such detailed care of forests as will be indicated later, but also the formation of forests where they do not exist, either because they have been removed ("deforestation") or because they have never existed on account of unfavorable conditions. The forester must keep in mind always the purposes of a forest in relation to human welfare, which are principally (1) a source of timber and other products, and (2) to check floods that carry off soil. He must also know the best ways of using forests,

and this includes "harvesting the crop," putting it into the necessary forms, and disposing of the products. The general motive of forestry, which runs through all of its details, is to use the forest in such a way that it may not only continue to be productive, but increasingly so. To insure this will require adequate protection of forest property, a more complete use of forest products, and harvesting with the future in mind.

126. **Character of the forest.** — An assemblage of trees is called a "stand," and stands may be pure or mixed. A pure stand is one in which all the trees, or nearly all, are of the same kind; while a mixed stand is one in which there are various kinds of trees. There are three parts of a forest to consider in forestry: (1) the canopy, (2) the forest floor, and (3) the character of the tree trunks, which represent the mass of wood.

The canopy is made up of the interlacing crowns of the trees, and it must be kept as uniform as possible. The value of the wood depends upon this, for a good canopy causes the lower branches to be shed while they are small, and as a result the trunk is clean and free from knots. In the formation of a forest, the forester sees to it that the canopy rises as the trees grow. In a pure forest a uniform canopy can be managed easily, but in a mixed forest the canopy is a more complex problem, for the different trees hold different relations to the light, some needing less light than others. In such a case the canopy is developed in stories in accordance with the light-needs of the different trees. The canopy serves several purposes in the economy of the forest. It manufactures the carbohydrate food for the trees; it shades the forest floor and thus prevents the development of undergrowth, checks the drying out of the soil, and shields the soil from dashing rains; it also enriches the soil with its leaf litter, making the forest soil the best of soils.

The forest floor is not merely the surface of the soil, but also the whole soil region in which the trees are rooted. This is usually deep and rich, but, more than all, the humus gives it the physical properties of a sponge in receiving and retaining water.

The character of the tree trunks is studied, not only to insure freedom from lower limbs by means of a suitable canopy, but also for the development of wood. Each tree has a period of development during which it adds annually to its wood mass enough to pay for the room and care it requires; but eventually it reaches a stage when it is not making enough wood "to pay for its keep." The time to use a tree, therefore, is when it has reached its maximum wood-production and has not yet begun to decline.

127. **Forests and floods.** — Forests not only build up and enrich the soil, but they also fix the soil, a fact of great importance especially in a hilly country. The interlacing roots grasp the soil, so that roots and soil are knit together in a mass that resists erosion. It can be observed that hillsides from which the forest has been removed soon become gullied and stripped of soil. This protection against erosion serves not only for the soil in which the forest grows, but also for the soil of the fields at the lower levels.

Forest soil holds water so persistently that heavy rains do not run off quickly and produce floods, as they do in bare regions. It is often remarked that streams that had a steady flow when a region was first settled have become alternately flooded and dry since the forests were removed. Therefore, the forest-covered soil not only prevents erosion of soil and flooded streams, but provides also a steady supply of water to the streams.

128. **Formation of forests.** — It would not be useful to give the details involved in the establishment of a forest where one does not exist, or in the making over of an inferior forest, but some idea of the things involved will add

to one's information as to the work of a forester. Sometimes the soil must be reclaimed by draining it if swampy, and by putting it into better physical condition if necessary. Great judgment must be used in the selection of trees for a given region, and in the decision whether it is better to establish a pure or a mixed forest. The seed used must be tested thoroughly for quality, and the care of seedlings is full of details. In general, the germination of seeds and the care of seedlings are best provided for in reliable nurseries. In making over a forest of inferior quality, the problem is to give seedlings a chance to grow and to replace the old and inferior trees by young and vigorous ones. Of course each forest has its own problems, but enough has been stated to indicate how a uniform stand may be secured in making or reclaiming a forest.

129. **Care of forests.** — The care of a forest means keeping it in good condition. " Cleaning " a forest means the removal of useless trees, useless because they are dead or injured or old or unpromising, and the removal of other plants and of brush that interfere with the proper condition of the forest floor. " Thinning " a forest means the removal of certain trees to prevent the trees from interfering with one another. This interference is mostly a question of an over-crowded canopy, for the crowns must expand freely and interlace, but must not interfere with one another's development. Sometimes pruning is helpful, but this is not practicable in a large forest as a general performance. The advantage of forest growth in the production of wood as contrasted with isolated trees should be understood. A tree " in the open " is often thought of as the best developed tree, which may be true so far as its general appearance is concerned; it satisfies best our idea of how a tree should look. But if a tree is expected to produce wood of good quality, it must be associated with other trees so that a good canopy is developed. A tree in the open produces

more wood, but it is poorer in quality because the lower limbs are allowed to develop and the wood is full of knots.

130. **Protection of forests.** — The protection of forests is one of the most difficult problems of forestry, for it involves the passing of laws and their enforcement, and the hearty coöperation of communities. This is especially true of protection against fire, which is the greatest enemy of the American forest, and is mostly the result of ignorance, carelessness, or indifference. The fierce fires in the white pine regions of Michigan, Wisconsin, and Minnesota have become familiar, and sometimes they involve extensive destruction not only of valuable trees, but also of human lives. In the great Minnesota fire of 1904 it is reported that 600 lives were lost. An investigation of the causes of these recurring forest fires has shown that sparks from passing locomotives are the chief cause. It is evident that this cause of fires can be controlled if public sentiment becomes strong enough. Another prolific cause of fires comes from the carelessness of campers and hunters, a cause that is troublesome to check. Farmers often "clear the land" by fire, and carelessness or lack of judgment may result in permitting the fire to extend into the adjacent forest. The effect of a fire differs in its destructiveness. It may involve only the canopy; it may run over the surface of the soil; or it may be fierce enough to burn the humus of the soil. In any case, the forest is crippled, and in the last case not only are the trees destroyed, but the soil is no longer fit for forest growth.

The danger of hard freezing is also to be considered, for it may kill the buds, crack the stems, and upheave the young plants. Frost cracks in lumber show that damage from this cause is often serious. The trees cannot be protected from such a danger completely, but a dense canopy reduces it, and a thick litter of decaying leaves (humus) on the forest floor is still further protection. Damage is also done by violent winds, hail storms, sleet, and snow, but

these are the accidents of nature that involve only a repair of the damage.

There are many insects which are very destructive to trees because they bore into the wood or eat the leaves. The gipsy moth has become famous for its leaf-destroying powers. The best protection against insects is to encourage their enemies. A forest full of birds, toads, snakes, etc., is well-protected against destructive insects. The need for such protection justifies the exclusion of hunters from forests under cultivation, especially the men who shoot at everything.

The problem of grazing animals in a forest is a mixed one. These animals are usually sheep, and up to a certain number they may not be injurious, and may even be helpful, but in large numbers they are injurious, being not only grazing but also browsing animals.

The danger to forests from plant diseases will be considered in the next chapter, which deals with plant diseases in general.

131. **Forest products.** — It is a surprise to many to discover the number of uses to which forest trees are put. Most people probably think of forests only as a source of lumber, so far as their commercial use is concerned. It is true that lumber is the conspicuous product, and it is known that this lumber is put to endless uses. For this purpose, trees are grouped as "soft woods" (pine, spruce, hemlock, cedar, etc.), belonging to the conifer group (called "evergreens" by many), and "hard woods" (oak, walnut, hickory, cherry, locust, tulip-tree, ash, maple, elm, cottonwood, etc.). The lumber industry in soft woods may be used as an illustration. The most prized soft wood is the white pine, and the important white pine states are Michigan, Wisconsin, and Minnesota. This valuable tree has been harvested so recklessly that it has now approached dangerously near the point of extinction as a commercial source of lumber. The lumber camps, logging operations, and the floating out of

the lumber are important features of these states, and have developed a type of life and a race of hardy men (chiefly French Canadians) who have appeared in many stories. In the south the yellow pine is the great soft wood. As it grows in an open, level forest, the logging operations differ from those of white pine, and are by no means so picturesque. The logs are simply hauled to the railway or mill, and the work is done chiefly by negroes. The third great region for soft wood lumber is in the northwest, in the Douglas spruce and redwood forests of the Pacific slope, where the immense size of the trees and the roughness of the ground have necessitated special methods and machinery entirely unknown in other regions.

The use of wood pulp in the manufacture of paper is a tremendous industry. The most commonly used wood is spruce, and the process consists in grinding the wood (from which bark and knots are removed) into pulp and pressing it into paper. This pressed pulp, aside from paper manufacture, is used in the manufacture of a great variety of articles, as buckets, doors, and even wheels. In the manufacture of paper it is estimated that one ton of paper pulp is produced by one and a half cords of wood. The amount of this paper used by newspapers is enormous. It has been estimated that one large newspaper uses in one year all the spruce grown on 16,000 acres of land, as spruce naturally grows. If this amount be multiplied so as to include all the newspapers, it is evident that the supply of spruce will fail. Of course other woods can be used for the same purpose, Carolina poplar making very good paper pulp.

The pines are used as the source of resin and turpentine, which occur in " crude resin " in the resin ducts of the wood. The largest supply of this product comes from the pine forests of the south, but in collecting it the trees are so handled that they are destroyed. In France the product is obtained without destroying the trees, and unless some such method

is introduced in the southern pineries, the resin industry is doomed to destruction.

The bark of certain trees is also used as a source of tannic acid for tanning leather. In Europe, oaks are extensively propagated for this purpose, but in the United States hemlock bark is used. With our usual recklessness the trees are practically destroyed in securing the bark, so that now a large amount of our tannin comes from South American woods.

The destructive distillation of woods yields a remarkable variety of products that need not be enumerated, chief among which are wood alcohol and tar (from the distillation of pine). In every case, after the desired product has been driven off by distillation, charcoal is left.

Any consideration of the products of trees must include maple sugar and syrup. This is said to be the only forest industry that has been developed on a scientific basis. It is an American industry, and when it is known that over 50,000,000 pounds of sugar and 3,000,000 gallons of syrup are produced each year, it can be appreciated that the industry is a large one. Vermont is the leading state in maple sugar production, producing 15,000,000 pounds of sugar and 100,000 gallons of syrup in a year.

In this connection mention may be made of the common sources of commercial sugar. Sugar-cane (a grass) has been used longest as a source of sugar, and in this country the industry has been most developed in Louisiana. The manufacture of sugar from beets is a much newer industry, and has developed on a large scale in the United States. In the production of sugar from sugar-cane, India leads the other countries, followed by Cuba, Java, and the United States. The world's production of sugar from cane in 1903 is estimated to have been about 4,000,000 tons; and of sugar from beets about 5,800,000 tons, 5,600,000 tons of which was produced in Europe. In 1911 the production of sugar from

cane had reached 7,600,000 tons, and from beets 8,400,000 tons.

Another use of forest products has yet to be developed in the United States. In Europe every twig is used; that is, the forest refuse, which we destroy as "brush," is all utilized. To use this material seems to the American a waste of time, involving an amount of labor that is not paid for by the result; but since many uses for forest refuse have been developed in European countries, there is no reason why some of them may not be introduced here.

132. **Forest reservations.** — The great importance of exercising some control over forests has led the national government to adopt a system of forest reservations, which are under its care. To a certain extent, states have done the same thing, but it will be impossible to include them in this brief statement. It is not the purpose of the government to withdraw such forests from use, but rather to supervise their use so that they may continue to be productive. Furthermore, some forests are reserved by the government not so much for the sake of a continuous timber supply, as to protect certain regions from floods and soil destruction. Naturally such forests are found on the important watersheds of our drainage systems.

These reservations are so fluctuating in extent, depending upon the attitude of the president towards forest reservation, that it is impossible to give their exact extent as a general statement. Some conception of the forest areas involved, however, and their distribution may be obtained from the following statement of the reservations in 1901, the beginning of such reservations being in 1891. The statement, therefore, covers the period of the first ten years of forest reservation. During that period nearly 50,000,000 acres of forest land were reserved, distributed among 13 states. The list of states, the number of reservations, and the approximate number of acres involved are as follows, in

the order of total size of area in each state: California, nine reservations, 8,750,000 acres; Washington, three reservations, 7,000,000 acres; Arizona, four reservations, 5,000,000 acres; Oregon, three reservations, 4,750,000 acres; Montana, three reservations, 4,500,000 acres; Idaho and Montana, one reservation in common, 4,000,000 acres; Wyoming, four reservations, 3,250,000 acres; Colorado, five reservations, 3,000,000 acres; New Mexico, two reservations, 2,750,000 acres; South Dakota and Wyoming, Black Hills reservation, 1,200,000 acres; Utah, three reservations, 1,000,000 acres; Idaho and Washington, one reservation in common, 650,000 acres; Alaska, one reservation, 400,000 acres; Oklahoma, one reservation, 60,000 acres. This list includes 41 reservations set apart as forests; but since 1901 the amount of reservation has been very much increased, the total area in 1912 approximating 190,000,000 acres. An illustration of the increase can be obtained from Alaska, whose area of reservation increased from 400,000 acres in 1901 to 27,000,000 acres in 1912.

133. **Street trees.** — Even though the reader of this book may not have access to a forest, where forest conditions can be observed, he can at least observe trees growing in yards or along streets. In fact, the study of trees, even in cities, is not only possible, but interesting and profitable. There is nothing more neglected than street trees, and it will be helpful if school pupils are taught to know something about their care.

The streets fitted for tree-planting usually provide a planting strip between the sidewalk and the curb; and in a very wide street a parking strip in the middle is often seen. Much street planting has been done independently by the owners of different lots, so that the trees are of various kinds and the result is a ragged appearance. If possible, a reasonable uniformity in the kind of tree used improves the appearance of a street very much. Not only should the trees be of the same kind, but their spacing should be uniform,

and this differs for different trees. The spacing should be a little greater than the natural spread of a tree; for example, the following spacings are recommended: white elm, 50 feet; maples, 40–45 feet (dependent on the kind); linden, 40 feet; Carolina poplar, 30 feet.

The selection of trees is important, and the judgment of different people will vary. The primary choice is between a fast-growing tree and a slow-growing tree. The former brings results quicker, which mean beauty and shade, but it is usually a short-lived and brittle tree. The latter develops beauty and shade very slowly, but it is usually long-lived and tougher. It would seem wise to select for city streets the slow-growing and long-lived trees, the most popular of which is the white or American elm. The rapid-growing trees, which impatient people select, are usually Carolina poplar, willow, box elder, or silver maple.

134. **Planting street trees.** — The space for soil preparation is very restricted, so that instead of breaking up the soil in the usual way for a crop, large holes are dug and filled with proper soil, which in this case means a pulverized soil thoroughly mixed with fine manure. Great care must be taken to see that there is proper drainage, and often a tile drain has to be laid. The young trees are usually obtained from a nursery, and before they are "set," they are pruned, so that the stem system may balance better the more or less injured root system. In case the root system is complete, no trimming is necessary, but it would be a rare amount of care that could transplant a young tree without injuring the roots more or less. In the bottom of the hole a bed of fine soil is placed, the tree is settled in place carefully and watered, and the hole filled up. Of course trees must be transplanted while they are dormant, and this means either spring-planting or fall-planting, the former being the better. Sometimes very large trees are transplanted, but the larger the tree, the greater the danger.

135. **Care of street trees.** — In observing most street trees, one might infer that after the trees are planted they need no attention. While they need little attention after they are full grown, the young and growing trees cannot be neglected. Perhaps the greatest cause of failure in the growing of street trees is the poor physical condition of the soil, a thing which the reader of this book might infer. The soil, therefore, must be kept in good physical condition around the young trees, and since the feeding ground of street trees is much restricted, certain fertilizers are a great help. It is evident that the cultivation of the soil beneath the tree helps the movement of air through the soil and helps the soil retain moisture. If there is sod around a tree, it should be broken up every few years.

Of course street trees must be pruned, and pruning is done while the tree is dormant. In connection with pruning, the large wounds (over two inches in diameter) must be cared for, or they will permit the entrance of destructive fungi. They are dressed with something that excludes fungi, as thick paint or coal tar. When a wound is very large (over six inches in diameter), it is usually covered after treatment with a zinc plate, a process called "tinning." Wounds less than two inches in diameter usually heal up before the fungi effect an entrance.

136. **Injuries to city trees.** — There are many sources of injury to city trees, due chiefly to city conditions. Smoke poured out abundantly from smoke stacks, and gas from leaking pipes escaping into the soil about the roots, are common causes of dead and dying trees seen along streets. Electric linemen are often reckless in chopping out branches to clear the way for wires. Trees are also often seen to be used for anchoring guy ropes. Regrading streets often destroys trees ruthlessly and needlessly. Ignorant pruning probably destroys more trees than any other danger, not only because the pruning is wrong, but also because the

wounds are not cared for. The old days of using trees for hitching posts and subjecting them to wounding by horse bites have nearly passed. Of course storms are to be reckoned with, and a sheeting of ice breaks many twigs and even large limbs. The best protection against damage from such storms is to select for street trees those that are not brittle. The Carolina poplar, willow, and silver maple are notably brittle, and after a storm the ground beneath them is strewn with a litter of branches.

137. **Suggestions for work.** — If a forest is available, it should be visited by all means. The trees should be named, the crown examined, the uniformity or irregularity of growth noted, and judgment passed as to the condition of the forest and its needs.

Special pains should be taken to learn to recognize all the common street and yard trees in the vicinity, both in their winter condition (from their habit and bark) and foliage condition. Street trees should be examined to discover their condition and the care they are receiving; if any work is being done with them, it should be watched. If trees are sickly looking, the cause should be inquired into. This kind of interest in street trees will stimulate the community to a more intelligent care of them.

CHAPTER XIII

PLANT DISEASES

138. **Definition.** — In the cultivation of plants there must be some knowledge of the diseases to which they are subject. Sometimes whole crops are destroyed by some disease, or at least much reduced in quantity and quality. The great losses from this cause have led the national and state governments to provide for the study of plant diseases in the hope of preventing them. Very much has been accomplished, but very much more remains to be done. A multitude of facts in reference to diseases and treatments have been accumulated, but these cannot be detailed here. Only the general facts in reference to plant diseases and the general principles of treatment can be indicated; for special details the student must consult the larger works in which the known facts are assembled.

It is difficult to define exactly what is meant by a plant "disease." In a large sense it is anything that interferes with the normal activities of a plant, so that it is not "doing well." It is evident that this would include a great variety of causes, such as soil conditions, climatic conditions, mechanical injuries, attacks of animals (especially insects), and attacks of parasitic fungi; in fact, anything that affects unfavorably the vigor of a plant. It is clear that we can include no such indefinite range of causes, and must restrict ourselves to the diseases induced by parasitic fungi, for these are the most common and most studied of the diseases.

The distinction between a disease and its cause must be kept clear. A parasite (like wheat rust, for example) is a cause, but the disease is the condition of the attacked plant

(host) brought about by the presence of the parasite, a condition which is more or less unfavorable to the work of the plant. This means that while we investigate the parasite to discover its habits, the patient that has the disease is the host plant. The study of plant diseases, therefore, so far as plant parasites are concerned, is the study of the effect of the parasite on the host plant.

The practical application of our knowledge of parasites and diseases has not resulted so much in curing diseases as in preventing them, which means preventing the attack of parasites. This involves enough knowledge of the parasite to know the form in which it makes its attack, as well as the part attacked and the time of attack.

139. **The groups of parasites.** — Almost all of the groups of fungi contain parasites that are dangerous to cultivated plants. These parasites are more or less selective, that is, they do not all attack all plants indiscriminately. Each parasite is more or less restricted to certain hosts, and often to a single host. This explains why one kind of plant is subject to a certain disease ("susceptible"), and another is not ("immune").

The groups of parasites are very numerous, and it would be impossible for an elementary student to learn to recognize them; but this is not important for our purpose. All that is necessary in this first contact is to learn to recognize certain "symptoms" of disease which attacked plants show. Any symptom suggests troubles which may be brought about by a great variety of parasites, and it is not always necessary to distinguish the parasite exactly before using the appropriate preventive measures.

140. **The groups of diseases.** — All plant diseases can be referred to three groups, which differ as to the relation of parasite and host.

In one group, the parasite kills living cells, and its destructiveness depends upon the number and kind of cells

killed. A plant attacked by such a parasite may live along in a more or less enfeebled way, or it may be destroyed completely.

In a second group, the parasite does not kill living cells, but lives in association with them, feeding upon their prod-

Fig. 83. — A spot disease of apple leaf. — After Sorauer.

ucts. Often as a result of the presence of such a parasite, the living cells are "stimulated" into doing unusual things, such as the development of "galls" or other unusual growths. Such growths are symptoms of the presence of such a parasite. This peaceful living together is usually brought to an end when the parasite begins to form spores.

In a third group the parasites neither destroy living cells nor live peaceably with them, but invade the water-conducting vessels (woody fibres) and live in the sap. This interferes with the movement of water, and if the parasites develop so as to block the vessels, the water supply is cut off and the plant wilts. These " wilt diseases " are very common and destructive, especially in the case of seedlings.

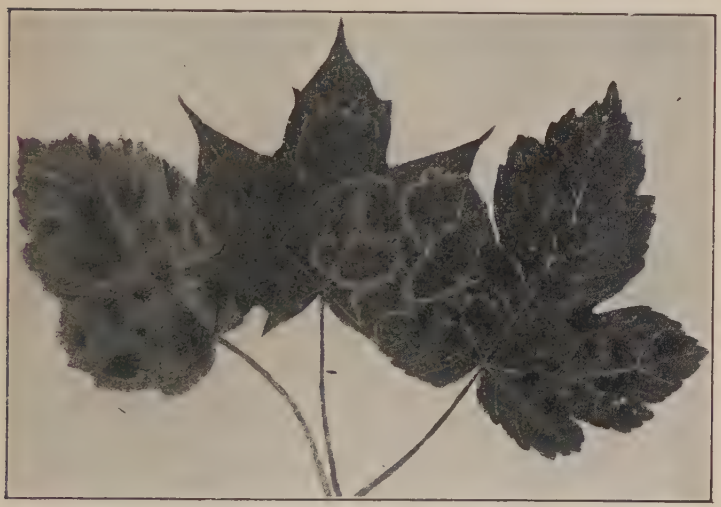


FIG. 84. — A spot disease of maple leaf. — After SORAUER.

141. **Diseases of the first group.** — In this group of diseases the parasite kills living cells. No list of these diseases can be given, but a few representative cases will illustrate them.

Pear blight. — This is one of the common diseases, not only of pear trees, but of apple trees and other fruit trees. It is sometimes called " fire blight " or " twig blight," and these names suggest the appearance of trees with this disease. The flowers and branch tips begin to wilt and finally blacken, and this may extend to every branch tip, until the

tree appears as though its branches had been badly scorched with fire. This disease is caused by certain bacteria that spread through the living cells and destroy them. It is always necessary to determine how a parasite effects an entrance in a plant, for this suggests the method of prevention. The entrance of a parasite is spoken of as an "infec-

Fig. 85. — A spot disease of currant leaf. — After Hall.

tion," and in the case of pear blight, it is found that the infection is brought about by insects (especially bees) visiting the flowers. This infection spreads to other flowers and through them into the young twigs. Just how the insects get the bacteria is a detail that is not needed for practical purposes.

Spot diseases. — It is very common to see leaves spotted,

the spots indicating that they have been attacked by some fungus (Figs. 83–87). Among the parasites that produce spotted leaves are the "mildews." One kind of mildew is called the "downy mildew" because it appears on the surface (usually leaf) of the host plant as small downy patches.

FIG. 86. — A spot disease of strawberry leaves. — After MASSEE.

These patches are numerous minute branches bearing spores, that have arisen from the parasite deep within the host, where it is destroying living cells. Before the downy patches appear, the presence of such a parasite in a leaf is shown by the dying and dead spots. This attack on leaves reduces their ability to manufacture food, and it may be so general an attack that the leaves are destroyed entirely. Such

attacks are common on many vegetables, as radishes, turnips, cucumbers, onions, lettuce, etc., but the most conspicuous case is that of the grape (Fig. 88).

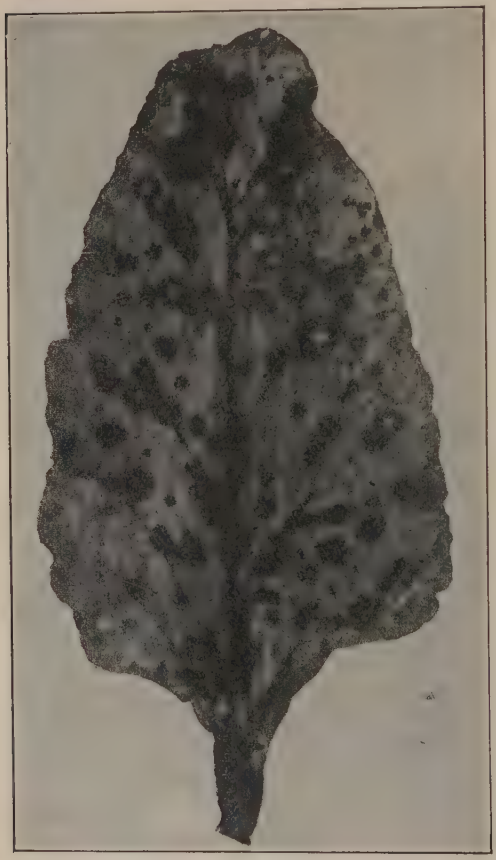


Fig. 87. — A spot disease of beet leaf. — After Halsted.

These mildews represent one of the most destructive of the "diseases" of the grape-vine, the most susceptible grape being the wine grape (*Vitis vinifera*) of Europe and California. In the account of the grape (p. 396) it was stated that the wine grape could not be grown in our eastern states on account of this disease. It can be grown in Europe and California because for some reason the destructive mildew is absent or is harmless. Infection in this case is by spores that fall upon young leaves, and the suggested prevention is to destroy the spores in some way before they can effect an entrance.

Another kind of mildew (" powdery mildew ") attacks the young grapes, producing corky spots that destroy the value

Fig. 88. — Grape leaf, showing patches of downy mildew.

of the fruit. This spotting of the fruit does not destroy the plant, for it is only a skin disease, but it destroys the value of the plant for our use.

Potato disease. — This is a notable and dangerous disease. Famines in Ireland have been brought about by its ravages, because in destroying the potato crop there were no other crops to replace it as a food supply. The spores of the parasite enter the young leaves and they begin to spot (Fig. 89), and finally the parasite invades all the leaves and the young stem, and the plant dies. The disease is so very epidemic that if it enters a potato field, it sweeps through it with great rapidity. If the attack is early in the season, the formation of tubers may be stopped; if it is later, the tubers may have begun to develop, and in this case the tubers also are invaded. Tubers in this condition are said to have the "potato rot" (Fig. 90), but the rotting is not caused by the destructive parasite; it is merely the natural rotting of a plant structure that has been killed. This is one of the hardest diseases to prevent, for since potatoes are propagated by tubers, the danger of infected tubers is very great.

FIG. 89. — Potato disease on the leaves. — After JONES.

Stone fruit diseases. — The common disease of stone fruits is the "brown rot," and probably its destructiveness is noticed more in the case of peaches than in any other one of the stone fruits (plum and cherry), many of the "failures" of the peach crop being due to it. Along with the peach

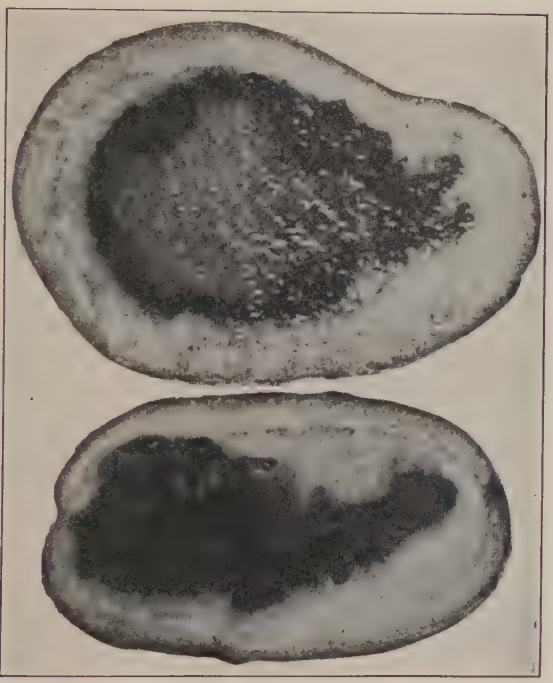


FIG. 90. — Potato disease ("potato rot") in tubers. — After DUGGAR.

are associated its near relatives, the apricot and the nectarine. In this case the fruit is infected directly by the spores of the parasite, and it seems to be most susceptible from the time it is half grown until it ripens. The first symptom of the attack is a small, brown, decayed spot which increases in size until the whole fruit is infected. Often the

fruit is completely dried out, and such "mummies," as they are called, may be seen hanging on the trees. It should be realized that these mummies are exceedingly dangerous, for they are the chief source of infection the next year. Often infections are so late that the disease is not detected until after the fruit is picked and shipped, in which case a lot of slightly specked fruits when shipped may arrive as mummies or nearly so.

FIG. 91.— Canker on apple tree.—After SORAUER.

Cankers.—These are diseases that arise in connection with open wounds, and are conspicuous in trees (Fig. 91). Some knowledge of cankers is of great practical importance in the handling of forests and orchards. As they are wound diseases, it is evident how the parasite enters, and the wounds are formed in nature by storms, and in cultivation by trimming and bruising. If the wound is small, it may heal naturally; but if it is large, it may remain as an open wound, exposed to continuous infection.

Bitter rot. — This is a very destructive disease of apples and other fruits, and is known wherever apples are cultivated. It is recognized by the characteristic spot it forms on apples. It is at first small, increases rapidly in size, turns

brown, and becomes sunken through rotting of the tissue (Fig. 92). These spots may be recognized from other kinds of spots by their sunken appearance, their bitter taste, and their ringed border. This disease was observed for many years before the method of infection was discovered. Now it is known that the parasite is a wound parasite that develops cankers on the twigs (Fig. 93). Abundant spores are formed in these cankers and are washed down by rains on the fruit

Fig. 92. — Bitter rot of apple. — After Clinton.

below. It had long been noticed that a sudden attack of bitter rot was brought about by a few rainy days.

142. **Diseases of the second group.** — In this group of diseases the parasite does not kill living cells, but lives on their products and often induces them to develop unusual structures.

Rust. — This is a very conspicuous disease of cereals, in which the parasite and host live peaceably together for a time, but in which there is usually no abnormal growth. The "disease," therefore, consists in the gradual weakening of the living cells by the drain upon their food supplies, until finally they can work no more and are destroyed by

the parasite. It is easy to discover this trouble, for the rusty patches of spores become abundant on the leaves and stem of the host plant, but the cure seems hopeless, and prevention is uncertain as yet.

Crown gall. — This is a very common bacterial disease of trees and shrubs, and among cultivated plants it is noteworthy in the various fruit trees and street trees. As the name implies, the symptom of the disease is the development of a gall-like growth (tumor) on the " crown " of the

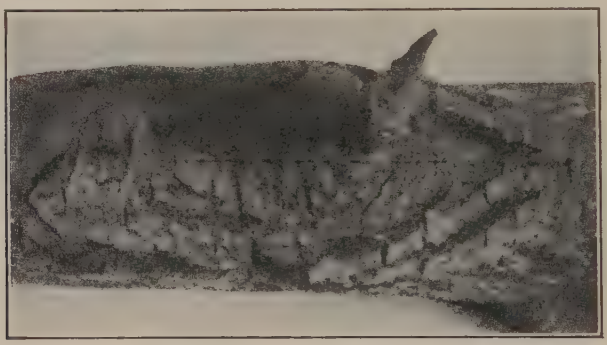


Fig. 93. — Canker of bitter rot on apple twigs. — After Burrill.

plant, which means the base of the stem where it joins the root (Fig. 94). During the autumn and winter the gall disintegrates and leaves an open wound. At the margin of an old gall, new galls arise, and so the wounds are enlarged from year to year.

A most interesting fact has been discovered in connection with these galls, and that is that they give rise to a disease-carrying tissue (" infecting strands ") that penetrates to other regions of the plant and gives rise to new galls. This makes it impossible to remove the trouble by surgery, for while galls may be removed and the wounds healed, the " infecting strands " are spreading the trouble into other regions. The whole trouble begins by some wounding or

bruising of the crown that permits the gall-forming bacteria to enter.

Peach leaf curl. — It is a frequent trouble in peach orchards that the leaves become curled up and twisted into various shapes, the surface looking wrinkled and blistered. This interferes with the work of the leaves so much that there may be an extensive failure of the crop. This curling and twisting is due to the fact that the presence of the parasite causes the leaf cells to grow very unevenly.

FIG. 94. — Crown gall on daisy. — After ERWIN SMITH.

Black knot. — This is an exceedingly common disease, and among cultivated plants it is most commonly seen on plum (Fig. 95, *a*) and cherry trees, but it is common also on shrubs, as currants (Fig. 95, *b*) and gooseberries. It appears as small hard knots or "warts" that break through the bark and finally become dark brown or black. The knot is made up of a mixed mass of cells developed by the host plant because of the presence of the fungus, and interlaced in the tissues of the knot is the thready body of the parasite. The twigs of the plant may not be killed, but when they are girdled by knots they are destroyed.

143. **Diseases of the third group.** — In this group of diseases the parasite invades the water-conducting vessels and

lives in the sap, cutting off the water supply and causing the host plant to wilt and die. Since the first symptom of the presence of these parasites is the wilting of the host, these diseases are known in general as "wilts." There are a great many kinds of wilt-producing fungi, but their relation to the host and their effect upon it are the same. A few illustrations will be given.

FIG. 95. — Black knot: *a*, on plum; *b*, on currant. — After MASSEE.

Cabbage wilt. — In this disease, the water-conducting vessels are invaded by bacteria that enter through the "water pores" of the leaves, which are minute openings along the edges of the leaves that are connected with the system of water-conducting vessels. They are in fact the open terminals of this system. The disease is often called the "black rot of cabbage" (Fig. 96), but the rotting is not due to the wilt-producing bacteria, but to the decay of the leaves or of the whole head which they have been the means of killing.

Cucurbit wilt. — This is often a very destructive disease among melons and cucumbers. In this case there is no natural opening for the entrance of wilt-producing bacteria, as in cabbage, but the infection is through wounds produced by the bites of insects. From the point of entrance the infection extends through the vessel system. If the infection is at the tip of a branch, the wilting is gradual; if it is in the main stem, the wilting is rapid.

Fusarium wilts. — Bacteria are not the only fungi that

produce wilt diseases. Among the other wilt-producing forms are the Fusariums. Under this head come three diseases of great importance in the south, namely the wilts of cotton, cowpea, and watermelon. The *Fusarium* is a soil fungus, so that the infection is probably what is called a "soil-infection," the most difficult kind to guard against.

FIG. 96. — Black rot of cabbage. *c*, healthy plant; *s*, diseased plant. — After HARDING.

It means that the soil of a field becomes infected, and that continued planting on that area simply increases the infected area every year. Another notable Fusarium wilt is the flax wilt, which is the great enemy to the raising of flax. Fusarium-infected soils are often spoken of as "sick soils," as "cotton sick," "flax sick," etc.

Mushroom wilts. — These are our most important tree diseases, and since they are wood-destroying diseases, they are of great importance to the forester. The invading

fungus is a mushroom (Fig. 97), which enters the tree by its spores lodging in wounds, or penetrates directly into the tree by way of the soil. In either event, the wood-vessels are invaded, and the destruction of wood is due to the action of substances formed by the fungus. In this way the various "rots" of trees are brought about.

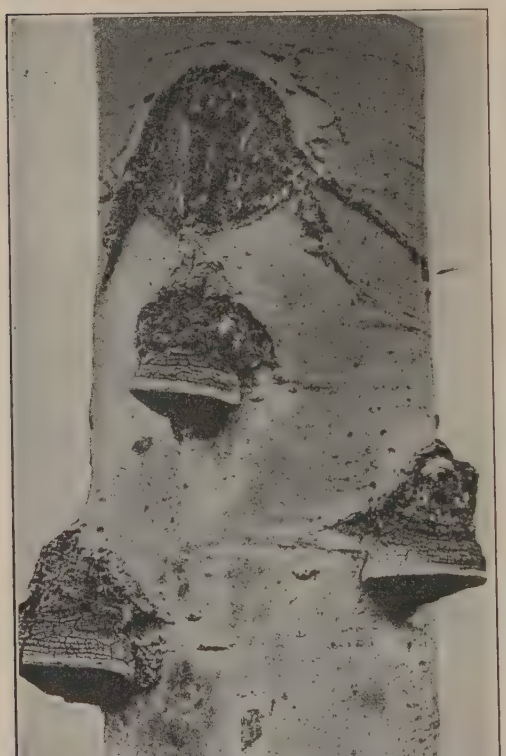


FIG. 97. — Tree fungus on aspen. — After VON SCHRENK and SPAULDING.

144. **Control of diseases.** — All of the study of plant diseases has for its purpose the control of diseases. It is evident that this is a vast and complicated subject. A great many "treatments" are suggested that are not based in knowledge; they may do good, or they may be useless. Naturally, people use any treatment that may do good, rather than no treatment at all. But as the knowledge of plant diseases increases, treatments are

becoming more and more intelligent and effective. There are a few general principles that lie at the basis of any intelligent and effective treatment, and these principles should be known to all who cultivate plants.

145. **Infection.** — No intelligent control of disease is possible without exact knowledge of the sources of infection. A good illustration of the truth of this statement may be obtained from the case of peach curl. For a long time it was supposed that the infection came from a parasite that lived year after year in the peach tree, and therefore that no control was possible. But when it was found that the infection came from spores that lodged on the buds, thus getting a chance at very young leaves, the control became obvious and easy.

It is well to recall the various sources of infection known, and to remember that they are not yet known in the case of most diseases. There are soil infections, the parasites living from season to season in the soil; spore infections, in which spores are carried by the wind, by insects, by raindrops, by seeds, etc.; wound infections; and infections by parasites that live from season to season in the host. There are also parasites on the surfaces of host plants, and parasites within the tissues of host plants; the former can be treated easily, and the latter not.

146. **Fungicides.** — A fungicide is a substance that kills fungi. It is applied usually either as a powder or as a liquid, and it is obvious that its application depends upon whether the fungus can be reached. The obvious conditions for application are when the parasite is a superficial one, or when its spores are lodged somewhere on the surface of the plant. Such applications are clearly not appropriate in the case of soil infections, or in the case of parasites living permanently within the tissues of the host. It should be remembered, also, that some fungicides injure some plants, so that their use upon them, no matter what may be the position of the parasite, is impossible.

The list of fungicides is a long one, and would not be appropriate here. Their names and their composition can be obtained easily if needed. The most famous and the most generally useful is called "Bordeaux mixture," which was discovered in connection with the ravaging of European vineyards by mildew. It is a mixture of copper sulphate and lime.

When it is discovered that a fungicide is appropriate, the next thing is to know when to apply it. This can be made plain by a few illustrations. The grape mildew infects the grape-vine by means of its spores falling upon young leaves. Accordingly, the young leaves are sprayed with the fungicide, and this treatment has proved to be completely effective in controlling the disease.

The case of potato disease ("potato rot") is somewhat different. Here also the disease is spread by wind-blown spores, which infect young leaves. Therefore, early spraying of potato plants with Bordeaux mixture checks the spread of the disease. But the more serious trouble comes from the infected tubers which pass the disease on from generation to generation. The fungicide treatment in this case, therefore, does not eliminate the disease, but simply checks its spread.

In the brown rot of stone fruits, the infecting spores are lodged on the bark and leaf buds. It follows that these spores should be destroyed by the application of a fungicide in late winter or early spring. In brown rot, in addition to spores lodged on bark and leaf buds, there is danger of infection from mummied fruits hanging on the twigs or fallen on the ground, and it is evident that all such fruits should be destroyed.

Of course the powdery mildews, such as attack grapes and induce a skin disease of the fruit, are easily reached and killed by a fungicide while the fruit is young.

These illustrations will serve to indicate what is meant

by the statement that fungicides are appropriate only for certain parasites; that in each case there is a most effective time for their application; and that in some cases they are only of supplementary use, not reaching all the sources of infection.

147. **Surgery.** — This means the removal of infection and guarding against further infection. Perhaps no treatment of plants is done more thoughtlessly and needlessly than surgery. Before any such operation, one must be sure of three things: (1) whether the infection exists in the part proposed to be removed; (2) if so, whether it will do any good to remove it; (3) and if so, whether it can be removed. A few illustrations will make this plain.

In the case of pear blight, the flowers are infected by insects that obtain the bacteria from certain affected branches in which they have passed the winter. It happens that these branches show their character, for they are "blighted." It is obvious that such branches must be pruned out before the opening of the flowers.

Crown gall was once thought to be a case for surgery, but now it is shown that the removal of a gall (tumor) is ineffective because there are infecting strands (p. 444) which cannot be removed. This illustrates a case in which the infected area is known, but it cannot be removed. The only surgery useful in crown gall is to destroy all affected nursery stock.

One of the most common applications of surgery is in connection with the treatment of wounds on trees, to prevent cankers and invasions of the water-conducting vessels. A race of "tree surgeons" has been developed, some of whom are reliable, and others are ignorant of their business. The general method is to clean out the wound so that a fresh surface is exposed for healing, and then to cover it so as to prevent the entrance of wound-infecting fungi.

148. **Soil infection.** — When soil infection is involved in

any disease, it is peculiarly hard to control. Once the use of soil fungicides was recommended, but since we have learned something about the soil, this has been shown to be a very dangerous proceeding. The soil is swarming with bacteria and other fungi, many of which are extremely important, and fungicides cannot pick out one organism for destruction and leave the others alive. Such a treatment is much like annihilating the population of a city to get at one criminal. There is no evidence, as yet, that any so-called soil fungicide does any good.

If fungicides are not available for soil infections, such as occur in numerous wilt diseases, what can be done? In the case of garden crops, as cabbage, infected plants can be removed or destroyed, but in the case of field crops this is impracticable. The only known method of controlling soil infection is to stop planting the susceptible crop on the infected area, and to plant some other crop. This rotation generally eliminates the infection or weakens it.

149. **Uninfected stock.** — In all cases of infection by parasites living from one season to the next in a plant, the only safe thing to do is to see to it that seeds or tubers or cuttings used in propagation are obtained from absolutely uninfected stock. This has been tried with the potato disease and found to be most effective.

150. **Resistant races.** — The breeding of races of plants resistant ("immune") to the different diseases is the final resort in the matter of control. When nothing else avails, the cultivation of immune races must be resorted to. Probably this will be the final remedy for all our plant diseases, but those that can be controlled can afford to wait. For this reason, the work on resistant races as yet has had to do chiefly with diseases that arise from soil infections. The following illustrations indicate that some progress has been made.

In the case of the potato disease it was shown how a

fungicide, like Bordeaux mixture, can be used on very young plants to reduce the spread of infection during a growing season; but the more serious trouble is in the soil, from infected tubers. It was in connection with this important disease that the first attempts were made to develop resistant races, and many have been obtained. The trouble has been that resistant races do not continue to be resistant, and in a few seasons they are no more resistant than other races. Also, the resistant races have not proved to be resistant in all localities.

In the case of the Fusarium wilts, as of cotton, the cultivation of resistant races began seven or eight years ago, and in four or five years success was attained. Several resistant races of cotton, and also of cowpea, were secured. As in the case of resistant races of potato, however, the resistant races of cotton have not always retained this character in all localities.

The discovery and development of a race of wheat resistant to rust have been described (p. 355).

The cultivation of races resistant to disease is very new work, but it promises to be the method by which we shall finally eliminate all the diseases of cultivated plants.

151. **Suggestions for work.** — Probably no work can be done with plant diseases except in learning to recognize some common diseases. As many cultivated plants as possible, including street trees, should be examined for diseases, especially for spotted leaves, wilts, galls, black knot, and cankers. All wild plants are subject to disease, and these might be used to extend the observations.

In addition to this, specimens showing the usual diseases of the common cultivated plants can probably be obtained by any school from its state Agricultural Experiment Station. These will serve as valuable guides to the recognition of these diseases among the plants cultivated in the neighborhood of the school.

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